THE UNIVERSITY OF WESTERN AUSTRALIA | Institute of Agriculture

Annual Research Report 2023

Sustaining productive agriculture for a growing world

Vision

Our vision is to empower communities and individuals in Australia and the Indian Ocean Rim to improve their food, nutritional and health security, enhance local and regional prosperity and exercise responsible environmental stewardship.

Mission

As an international leader in dryland agricultural systems, we develop and communicate innovative evidence-based solutions for ethical food production, environmental sustainability and agribusiness advancement in state, national and international settings that enrich peoples' lives.

Strategies

Integration

Bringing together UWA's agricultural research and communication activities; integrating complementary activities across disciplines and organisational units and providing a focus for leading-edge research and innovation.

Communication

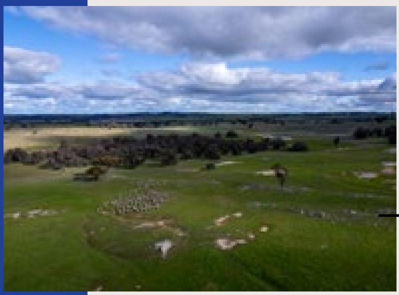
Strengthening links with regional industries, farmer groups and the broader regional, national and international scientific communities, in line with our Communications Plan.

Connecting

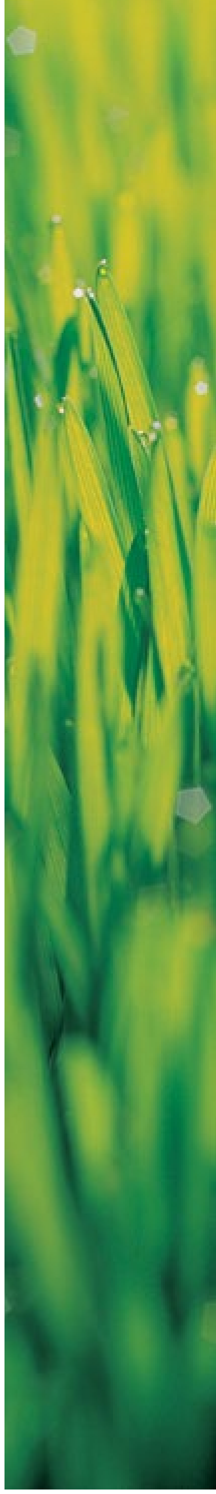
Fostering national and international linkages and alliances that bring new knowledge and expertise to WA and allow our institution to share its knowledge with the world.

Resourcing

Increasing the pool of resources available for investment in critical R&I in WA and relevant to national and international issues.



A flock of sheep move across a paddock at UWA Farm Ridgefield. Credit: Jarryd Gardner



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The UWA Institute of Agriculture Annual Research Report 2023

Director's overview

On behalf of The University of Western Australia (UWA), I am pleased to present the Annual Research Report 2023 for The UWA Institute of Agriculture (IOA).

This report highlights the remarkable achievements of our affiliated researchers and their collaborators, who collectively contributed to more than 297 journal articles, books, and book chapters in 2023. In addition to the numerous new PhD candidates who begun their journeys to becoming Drs this year, we also proudly recognise the many academics featured on the annual Highly Cited Researchers list, and those honoured with significant awards and accolades. Their commitment and hard work have undoubtedly played a crucial role in helping UWA maintain its position as the top-ranked institution nationally and 22nd globally for Agricultural Sciences in the 2023 Academic Ranking of World Universities.

Collaborative and multidisciplinary research and development activities were once again in the safe hands of the leaders of our six Research Themes: Sustainable Cropping Systems, Sustainable Animal Production Systems, Water for Food Production, Food Quality and Human Health, Engineering for Agriculture, and Agribusiness Ecosystems. This year, Adjunct Professor Keith Smettem completed his tenure as co-leader of Water for Food Production. The value of Adjunct Professor Smettem's dedication over so many years, since the inception of IOA, cannot be overstated.

In its first full year since launching in late 2022, the Best Practice Farming Systems (BPFS) Project grew from strength to strength. A standout occasion was the UWA Farm Ridgefield 2023 Open Day, where we welcomed more than 150 members of the agriculture, research, and local communities to the farm. I was especially proud to have The Nationals WA Member for Central Wheatbelt, the Hon. Mia Davies MLA, Pingelly Shire President Bill Mulroney, and UWA Vice Chancellor Professor Amit Chakma join in opening the event.

Thank you in particular to our hardworking Farm Manager Dr Tim Watts, research demonstrations site leaders, staff, and student volunteers whose efforts made the day a resounding success.

In 2023, we enhanced our engagement with industry, farmer groups, collaborators, funding bodies, and alumni through various communications and events. It was an exceptionally busy year, with IOA hosting and contributing to 19 public lectures, forums, seminars, and open days. We also saw a significant increase in engagement with UWA's agricultural research, development, and training initiatives. Our online presence expanded locally and across all corners of the globe – with LinkedIn followers near-doubling to 4,907. Thirty media statements related to IOA were distributed, generating excellent coverage in WA, interstate, and international media. These news articles attracted nearly 20,000 views online, with each UWA Impact story garnering several hundred views on average.

As we close out 2023 within the many pages of this Annual Research Report, I wish to shine the spotlight on our IOA staff, researchers, associates, students, board members, and Research Theme leaders, along with national and international collaborators and funding bodies. Your commitment and contributions have been invaluable to our collective success. Together, we have achieved remarkable milestones, and I'm deeply grateful for the partnership and collaboration that made it all possible.

Professor Kadambot Siddique
AM, CitWA, FTSE, FAIA, FNAAS, FAAS, FPAS, FTWAS
Hackett Professor of Agriculture Chair and Director

The UWA Institute of Agriculture
The University of Western Australia

IAB Chair and DVCR messages

As I reflect on 2023, I am once again filled with pride that the Industry Advisory Board (IAB) has assisted the IOA in maintaining and extending its relationship with the agricultural sector in WA. Comprising of passionate farmers and key industry representatives, our Board provides crucial advice and support, which greatly enhances IOA's overall impact and value to rural and regional communities in WA, Australia, and globally.

More than 230 people attended the 17th annual Industry Forum in July. Each year, the IAB forms a planning subcommittee to identify the timely topic and expert speakers for the Forum. It was clear that exploring 'Paving the way for the future of WA agriculture' struck a special chord with many in the audience. In her first official visit to UWA since being appointed Agriculture Minister, the Hon. Jackie Jarvis presented the formal opening speech, followed by a passionate keynote from WAFarmers chief executive Trevor Whittington. This event would not be possible without the long-time sponsorship and support of the CSBP and Farmers Golden Jubilee of Agriculture Science Fellowship.

It was my great pleasure to attend the UWA Farm Ridgefield 2023 Open Day in October. As a long-time farmer and having spent most of my life working alongside and interacting with grains and livestock producers, it was very rewarding to witness first-hand some of the innovative research projects underway at the farm in West Pingelly. I especially enjoyed hearing UWA Emerita Professor Lynette Abbott present on her FutureCarbon13 Project 2023-2028, the latest on 'Predicting nitrogen cycling and losses in Australian cropping systems' led by Associate Professor Louise Barton, and Associate Professor Dominique Blache and Dr Kelsey Pool's important work on sheep heat stress and fertility, respectively. Congratulations to all those who presented, and I look forward to receiving updates on these projects' findings and overall impact.

As we look forward to the coming year, I am filled with optimism for the IAB and IOA to continue to build upon its long-standing partnership and achieve our shared goals. Thank you to all members of the IAB, IOA contributors, and Director Hackett Professor Kadambot Siddique and his team.

Dr Terry Enright
Chair of the IOA Industry Advisory Board

The UWA Institute of Agriculture is one of two established strategic research institutes at The University of Western Australia and is a strong contributor to our mission as a comprehensive, research-intensive university. UWA maintained its number one position in Australia for agricultural science in 2023, and agriculture at UWA also achieved an impressive international ranking of 22nd, according to the Shanghai Academic Ranking of World Universities 2023.

The UWA Institute of Agriculture (IOA) has played a substantial role in developing this strength. It brings researchers and leaders from across numerous schools at the university to focus on critical priorities such as environmental and agricultural sustainability, food security, social impact, big data, understanding and overcoming the effects of climate change and more. Passionate and hardworking early career researchers, in particular PhD candidates, are strongly represented in the successes and achievements within this annual report.

I acknowledge and celebrate the researchers in agriculture and related areas who have made significant contributions to solving real-world challenges across 2023. A memorable highlight was IOA Director and Hackett Professor Kadambot Siddique being honoured as the 2023 Scientist of the Year at the Western Australian Premier's Science Awards.

I am pleased that the IOA disseminates research outcomes and engagement activities through regular media statements, social media, events, and publications which are important tools towards ultimate adoption and translation. I extend my thanks to the IOA for its work in 2023 and look forward to seeing affiliated researchers continue to push the boundaries of knowledge and innovation.

Professor Anna Nowak
Deputy Vice-Chancellor (Research)
The University of Western Australia

UWA PhD candidate Amber Balfour-Cunningham using a sweep net to sample for canola insect pests and natural enemies. *See page 40*

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Sustainable Cropping Systems

The Sustainable Cropping Systems theme covers all aspects of crop production, both above ground and below ground. Participants in the theme work across a broad scale, from genomics and plant physiology to crop breeding and field agronomy. Projects are generally multidisciplinary and involve collaboration among several UWA schools, farmer groups, DPIRD, CSIRO, Curtin and Murdoch universities, and interstate and overseas institutions. Many projects include industry partners, such as breeding companies and are designed specifically to meet their needs. Research also often involves collaboration with UWA adjuncts, who we highly value for their significant contributions to this theme. We are proud that most projects include a training component by including postgraduate students, commonly Master's by coursework and dissertation project students and PhD students.

As is evident from the projects in our section of the annual report, we research a broad range of crops, including wheat, barley, canola, lupins, chickpea, field pea, rice and pasture legumes. New and emerging crops are also often a focus. Research is generally targeted at the dryland farming systems of WA and southern Australia. However, northern Australia and our neighbours in Asia including China, Timor Leste, Bangladesh, India and Vietnam are also included in these studies.

UWA researchers are involved in projects focussed on topical areas, including maximising sustainable yield, thermal tolerance (frost and heat), crop water use efficiency, disease susceptibility/resistance, use of UAVs, big data and precision agriculture. UWA is also fortunate to have world-class facilities, and significant research strength, in genomics and other technologies applicable to crop breeding, including accelerated single-seed descent and speed breeding. A particular focus is placed upon root and rhizosphere biology, including root architecture and the role of roots in stress tolerance (e.g., to waterlogging, salinity, drought, and aluminium and manganese toxicities). How crop nutrient acquisition can be enhanced, particularly that of phosphorus and nitrogen, is also a focus: root morphological, physiological, and symbiotic mechanisms are all considered. In addition, we investigate the broader community of micro-organisms in the rhizosphere and their interaction with the plant. Many studies utilise our excellent Plant Growth Facilities, however, field relevance is always key and, whenever possible, research is extended to field conditions.

Overall, in this theme, we range from fundamental to highly applied agronomic research. However, we are cognisant of the needs of the industries and farmers who will ultimately apply our research outcomes to their farming systems.

Theme Leaders

Associate Professor Nicolas Taylor
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Professor Jacqueline Batley
School of Biological Sciences
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Dr Sun Kumar Gurung and Courtney De Mascio harvesting the glasshouse experiment.

Soil Science Challenge Project: Soil biological mechanisms underpinning the effects of biological amendments on soil health, productivity and resilience

Project team: Dr Sasha Jenkins[1] (project leader; sasha.jenkins@uwa.edu.au), Emerita Professor Lynette Abbott[1], Distinguished Professor Brajesh Singh[2], Professor Petra Marschner[3], Professor Nanthi Bolan[1], Professor Marit Kragt[1], Dr Bede Mickan[1,4], Dr Zakaria Solaiman[1], Hackett Professor Kadambot Siddique[1], Associate Professor Matthias Leopold[1], Associate Professor Louise Barton[1], Dr Hira Shaukat[1], Dr Allie Zheng[1], Dr Pankaj Singh[1], Dr Sun Kumar Gurung[1], Dr Juntao Wang[2], Thi Hoang Ha Truong[3]

Collaborating organisations: [1]UWA; [2]Western Sydney University; [3]The University of Adelaide; [4]Richgro

Emerita Professor Lynette Abbott and Torben Grell characterising the field soil.

Biological amendments can improve soil health and crop performance. Waste technologies (anaerobic digestion, composting, palletisation) convert organic materials into soil improvers that do not have balanced plant nutrient requirements. They can complement chemical fertilisers and contribute to soil resilience beyond overcoming nutrient constraints.

Many claims that soil biological amendments improve soil health and crop performance are unsupported. We will characterise underlying soil biological mechanisms associated with soil physical and chemical processes in terms of persistent contributions to soil health. A deep mechanistic understanding of this aspect of soil biology will enable transferability of knowledge of soil biological fertility across a spectrum of biological inputs that complement chemical fertilisers. The project will identify principles of effective and economic combinations of biological and chemical fertilisers and determine the underlying mechanisms involved.

The Soil Science Challenge Project investigates:

i) Mechanisms underpinning the impacts of biological amendments on relative contributions of bacteria and fungi to carbon and nutrient (N and P) cycling,
ii) Baseline soil bacterial and fungal responses to nutrient sources derived from waste technologies as complements to chemical fertilisers,
iii) Impacts of biological amendments on microbial diversity and soil health across soil types, land use and environmental conditions,
iv) Impacts of long-term application of compost on plant productivity under water constraints (drought, intermittent water deficit and water repellence),
v) Impacts of biological amendments on soil carbon dynamics and effects on microhabitats for soil biology, and
vi) Modelling of carbon from bacterial and fungal responses to coapplication of biological and chemical amendments to soil and the economic and environmental benefits.

A workshop for the Soil Science Challenge was held in 2023. The objective of the workshop was to identify gaps and opportunities for incorporation of knowledge of soil biology and nutrient cycling into conceptual models and partitioning of soil carbon, including the trade-offs between costs and benefits of applying soil amendments in relation to other management strategies.

This research is supported by UWA and the Department of Agriculture, Fisheries and Forestry.

Grazing into the future for soil carbon sequestration and building soil health with pasture biodiversity management

FutureCarbon13 field trial at UWA Farm Ridgefield with soil amendments applied to either annual or mixed perennial and annual pasture species.

Project team: Emerita Professor Lynette Abbott[1] (project leader; lynette.abbott@uwa.edu.au), Dr Zakaria Solaiman[1], Professor Nanthi Bolan[1], Hackett Professor Kadambot Siddique[1], Professor Philip Vercoe[1], Dr Sasha Jenkins[1], Dr Bede Mickan[1,4], Professor Marit Kragt[1], Associate Professor Matthias Leopold[1], Dr Natasha Pauli[1], Dr Tim Overheu[2], Dr Shabah Pathan[2], Phil Barrett-Lennard[3]

Collaborating organisations: [1]UWA; [2]WA Department of Primary Industries and Regional Development (DPIRD); [3]AgVivo; [4]Richgro

This project is investigating and documenting the potential for combining perennial and annual pastures species in a medium to low rainfall zone to increase soil carbon sequestration with co-benefits of improved soil health, increased biodiversity and resilience of the farming system to climate change. Pasture management practices are being augmented using soil biological amendments including compost, biochar and digestate. The research is being conducted at the UWA Farm Ridgefield over a seven-year period as a component of the WA Government Carbon Farming and Land Restoration Program.

The perennial pasture species being used include Phalaris, rhodes grass and veldt grass. The annual pasture species include annual ryegrass and subterranean clover. The trial is located on an existing annual pasture and soil and pasture assessments are being monitored.

The aims of this research project are:

i) To demonstrate whether there is potential to increase soil carbon in mixed perennial and annual pastures compared with annual pasture alone,

ii) To demonstrate whether soil biological amendments can increase the rate of soil carbon sequestration under mixed perennial and annual pasture or annual pasture alone, and

iii) The assess co-benefits, including soil health benefits, of the soil amendments and inclusion of the perennial pasture species within an annual pasture.

This research is supported by UWA, DPIRD, and the Western Australian Carbon Farming and Land Restoration Program FutureCarbon13.

Emerita Professor Lynette Abbott presenting the soil carbon trial at the UWA Farm Ridgefield 2023 Open Day.

Research Officer Paul Damon testing the semi-open passive chamber method before commencing experiments.

Quantifying ammonia volatilisation from cropping soils following the application of lime and ammonium sulphate fertiliser in close succession

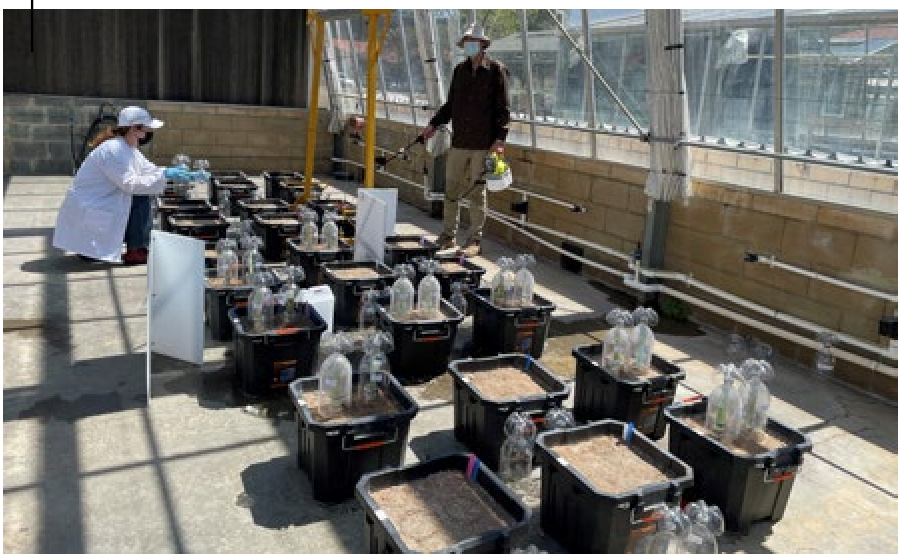
Project team: Associate Professor Louise Barton[1] (project leader; louise.barton@uwa.edu.au), Paul Damon[1], Professor Zed Rengel[1], Evonne Walker[1] Dr Fiona Dempster[1]

Collaborating organisations: [1]UWA; Murdoch University; SoilsWest; GRDC

Increased investment in fertiliser nitrogen (N) by grain growers has increased the imperative for fertiliser N use efficiency. Anecdotal evidence suggests broadcasting lime and ammonium sulphate in close succession onto dry soil prior to seeding is decreasing fertiliser N use efficiency in the Western Region due to ammonia volatilisation.

Our study investigated whether applying ammonium sulphate (100kg N/ha) to soils i) limed (2.5t/ha of lime sand) prior to planting canola (*Brassica napus* cv. ATR Stingray) (Experiment 1); or ii) containing residual lime (and having been 'cropped' once with canola) and planted to barley (*Hordeum vulgare* cv. Spartacus CL) (Experiment 2) increased the potential for ammonia volatilisation, and in turn decreased crop productivity and N uptake under two contrasting 'break-of-season' rainfall scenarios.

Paul Damon and Evonne Walker applying contrasting 'break-of-season' rainfall scenarios in the glasshouse.



The glasshouse study included two acidic Western Australian soils (Sodosol and Tenosol) and was conducted using large pots (300mm length x 300mm width x 300mm depth, containing 33kg of soil) that enabled plants to be grown in standard-spaced rows (170mm apart), and provided sufficient surface area for measuring ammonia volatilisation using a semi-open passive chamber method.

Our first experiment showed applying lime and ammonium sulphate to the soil surface in close succession prior to seeding increased the risk of ammonia volatilisation. Cumulative ammonia volatilisation losses after 21 days ranged from less than 1 per cent to 20 per cent of fertiliser N applied, depending on soil and treatment. Greatest losses from both soil types occurred when ammonium sulphate application onto a recently limed soil coincided with a series of 1mm simulated rainfall events. The extent of ammonia volatilisation from the limed soil significantly decreased (less than 7 per cent) if simulated rainfall (20mm) occurred immediately after ammonium sulphate application.

Our second experiment showed the risk of ammonia volatilisation persisted (up to 26 per cent of fertiliser N) when sulphate of ammonia was applied to the same two soils containing residual lime on the surface soil after harvesting a canola crop, and prior to planting a second crop (barley). The growth and grain yield of the canola and barley were not negatively impacted by the loss of N via ammonia volatilisation as there was sufficient plant-available N to maintain plant growth. Our study indicates growers should avoid spreading ammonium sulphate onto recently limed soils (or when there is residual lime on the soil surface) prior to seeding and when the soil is dry, unless confident that first rainfall events will be sufficient to cause the dissolved ammonium sulphate to move beyond the soil surface.

This research is supported by UWA and the Grains Research and Development Corporation (GRDC).

Predicting nitrogen cycling and losses in Australian cropping systems - Western Region

Project team: Associate Professor Louise Barton[1] (project leader; louise.barton@uwa.edu.au), Dr Craig Scanlan[2], Paul Damon[1], Dr Tan Dang[1]

Collaborating organisations: [1]UWA; [2]DPIRD; GDRC

Optimising nitrogen fertiliser use is important as it is an expensive input for crop production and represents the largest variable cost to growers. A national project funded by the GRDC aims to improve our understanding and model the fate of nitrogen fertiliser.

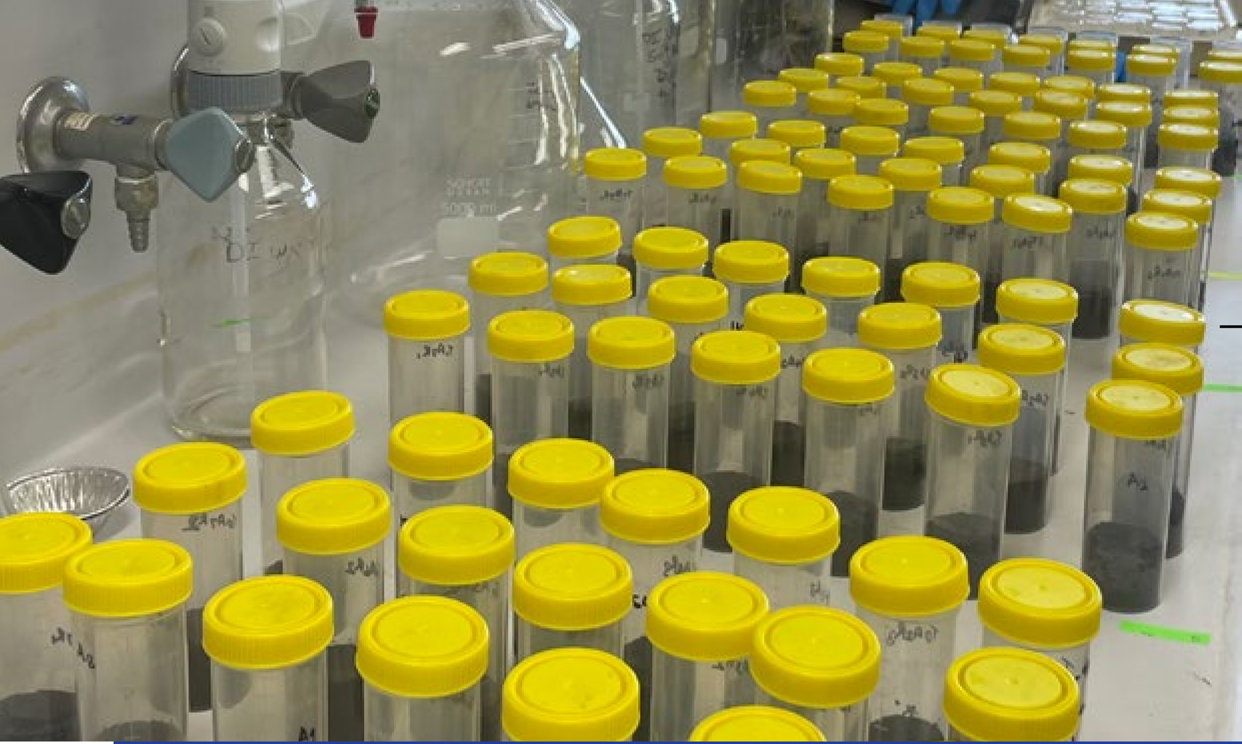
Twelve field trials commenced in 2023 across Australia, with four field trials being conducted in Western Australia (Esperance, Merredin, UWA Farm Ridgefield in Pingelly, and Wongan Hills) by UWA in partnership with DPIRD.

^{15}N-labelled fertiliser has been applied to crops at each location and will be tracked through the soil-plant system for three successive growing seasons. In Western Australia, the research is focusing on how much nitrogen fertiliser is taken up by wheat, how much is retained in the soil (and made available to subsequent crops), and to what extent it might move through the soil profile. Data from the project will also be used by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to improve the Agricultural Production Systems sIMulator (APSIM) model so that we can better forecast how much nitrogen fertiliser growers need to apply and when.

This research is supported by UWA, the GRDC, and DPIRD.

Field trial at UWA Farm Ridgefield.

Associate Professor Louise Barton presents her research demonstration to site visitors at the UWA Farm Ridgefield 2023 Open Day.



Nitrogen dynamics in soil amended with organano-mineral fertiliser - a laboratory soil incubation study.

Pilot to Paddock (P2P) - Innovative on-farm water, energy and nutrient technologies and practices for Australian dairy, egg, pork and cropping industries

Project team: Dr Sasha Jenkins[1] (project leader; sasha.jenkins@uwa.edu.au), Dr Sun Kumar Gurung[1], Emerita Professor Lynette Abbott[1], Ian Waite[1], Tammie Harold[1], Torben Grell[1], Dr Courtney Demascio[1], Dr Jen Middleton[2], Dr Bede Mickan[1,3], Dr Pankaj Singh[1]

Collaborating organisations: [1]UWA; [2]OOID Scientific; [3]Richgro

This project develops, demonstrates and promotes innovative water, energy and nutrient technologies, practices and products derived from waste to increase the productivity and profitability of the Australian dairy, pork, chicken (layer) and cropping industries whilst increasing resilience to climate change and lowering environmental impacts from reduced farm inputs, nutrient losses and greenhouse gas (GHG) emissions.

The project builds on the established partnerships of the successful National Agricultural Manure Management Program and involves several research partners. UWA is providing research services under the work package 'Novel fertiliser products for enhanced nutrient use efficiency' and contributes to other program activities, as needed.

The UWA team conducted a series of scientific literature reviews, including one on the potential impacts of soil biological amendments on microbial nutrient cycling pathways and soil health.

Experiments have been conducted on three dairy/pig farm soils with contrasting mineralogy. Glasshouse plant growth experiments and on-farm field trials obtained the soil and agronomic benefits as well as measured GHGs. For example, the research team investigated the response of plant and soil microbial communities to organo-mineral fertilisers as well as conducted bioinformatic, microbial genomic and plant data analysis.

Research activities are expected to complete mid-2024, and the results will be prepared, published, and communicated in late 2024.

This research is supported by the National Landcare Program's Smart Farming Partnerships. UWA has been subcontracted by the grantee Scolexia Pty Ltd.

Effects of organo-mineral fertiliser on plant growth under glasshouse condition.

All field plots (seven treatments x four replications) of the Shenton Park wheat trial.

Nutrient recovery from food waste anaerobic digestate

Project team: James O'Connor[1], Professor Nanthi Bolan (project leader; nanthi.bolan@uwa.edu.au), Dr Bede Mickan[1,2], Hackett Professor Kadambot Siddique[1], Associate Professor Matthias Leopold[1]

Collaborating organisations: [1]UWA; [2]Richgro

Improper disposal practices of food waste in landfills and incineration causes significant environmental, economic, and social challenges. Through effective food waste management practices, food waste can be valorised into a soil amendment that is a source of nutrients. Without, these management practices, application of food waste to soil causes phytotoxicity and can further cause environmental problems such as nutrient run-off. The valorisation of food waste into an organic amendment can occur through various processes such as composting, anaerobic digestion, thermal dehydration, pyrolysis, and chemical hydrolysis, altering the physio-chemical properties of the organic amendment.

Currently, composting is a conventional practice in food waste management. However, the practice can cause carbon dioxide emission and result in a large reduction in nitrogen from the substrate. Emerging practices of anaerobic digestion of food waste, can reduce the gaseous emissions (CH_4, H_2S, CO_2, NH_3, and N_2O) into the environment, and furthermore, retain nitrogen in the substrate in the form of ammonium.

This study comprehensively evaluates compost and anaerobic digestate on soil properties, N fertiliser interactions, gaseous emissions, plant growth and crop productivity. Moreover, the study synthesises novel food waste fertilisers derived from anaerobic digestate to improve its physico-chemical properties. These products retain ammonium during evaporation of raw liquid digestate and offer additional advantages by being solid (dewatered), lightweight, and enriched with improved nutrients. These products aim to improve logistical constraints currently faced by anaerobic digestion facilities.

The study indicated that anaerobic digestate had many advantages compared to composts for plant growth. Novel fertilisers were produced from anaerobic digestate to make it a more nutrient dense with enhanced nutrients. A solid, stable product was produced that can ease logistical bottlenecks at anaerobic digestion facilities. This not only permits safe on-site storage but also substantially cuts transportation costs from the facilities, enhancing overall efficiency and sustainability of food waste management.

This research is supported by UWA and Richgro.

Late vegetation stage of the Shenton Park wheat trial using novel food waste solid digestates.

Water industry members visit the experiment in a UWA glasshouse. From left; George Mercer (UWA), Rachel Major (WaterCorp), Kendall Ferraro (Tessele) and Sandra Henville (Water Research Australia).

Transforming biosolids into stable soil carbon

Project team: George Mercer[1] (project leader; george.mercer@research.uwa.edu.au), Professor Megan Ryan[1], Dr Bede Mickan[1,2], Associate Professor Deirdre Gleeson[1], Evonne Walker[1]

Collaborating organisations: [1]UWA; [2]Richgro; Water Corporation

This project forms part of the Australian Research Council (ARC) Centre for the Transformation of Australia's Biosolids Resource's theme 'Enhancing Product Applications' led by Professor Megan Ryan. Tim Healey Memorial Scholar George Mercer is the Industry Centre PhD student conducting the research, comprising three experimental packages which are now all complete.

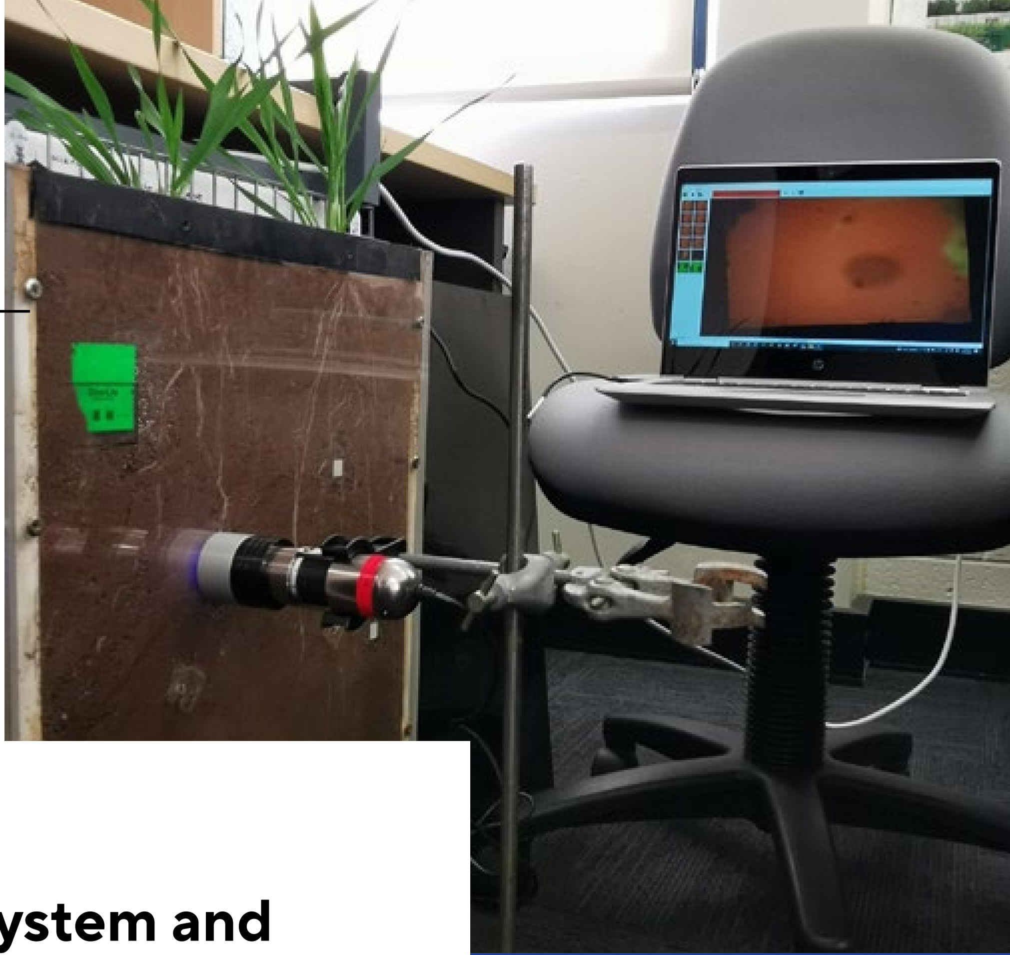
Wastewater biosolids can be transformed into value-added products that return carbon and nutrients to soils. The first experiment characterised the fine-fraction and total carbon response to three products; biosolids composted with green waste, dried biosolids and biosolids biochar. Soil microbes were observed to mineralise nutrients from these amendments, providing a plant growth benefit to perennial ryegrass when applied at seeding, at the cost of soil carbon.

The second experiment investigated the soil microbial response to amendments in the absence of a plant in a controlled soil microcosm. Without ongoing access to labile rhizosphere exudates, microbes were forced to use carbon more efficiently and were less capable of accessing the more thermodynamically recalcitrant organic matter, resulting in a net soil carbon gain.

By exploring different scenarios of rate, blend and nutrient stoichiometry, experiment three demonstrated that the delivery of these products can be optimised for desired parameters such as carbon use efficiency, net carbon storage, plant yield and soil constraints, providing evidence for beneficial reuse of transformed biosolids products in precision agricultural scenarios.

Mr Mercer received an AW Howard Travel Scholarship to present his results at the 9th International Symposium on Soil Organic Matter in Morrocco, where he received a 'Best oral presentation' award.

This research is supported by UWA, the ARC Centre for the Transformation of Australia's Biosolids Resource, AW Howard Trust, and Water Research Australia.



Imaging rhizosphere pH alteration during wheat plant growth using VisiSens imaging system coupled with optically polyester foils and rhizobox system.

Advancing root system and rhizosphere imaging platforms

Project team: Dr Yinglong Chen[1] (project leader; yinglong.chen @uwa.edu.au), Hackett Professor Kadambot Siddique[1], Professor Zed Rengel[1], Dr Jeremy Shaw[1], Associate Professor Peta Clode[1], Professor Davey Jones[2], Professor Malcolm Bennett[3], Professor Jonathan Lynch[4], Professor Bahar S. Razavi[5], Dr Haoyu Lou[6]

Collaborating organisations: [1]UWA; [2]Bangor University, Wales; [3]University of Nottingham, UK; [4]Penn State University, USA; [5]University of Kiel, Germany; [6]The University of Adelaide

Root system architecture (RSA) exerts a profound influence on plant water and nutrient uptake, thereby significantly impacting crop productivity. Moreover, the rhizosphere, where intricate interactions unfold among plants, soil, and microorganisms, plays a pivotal role in nutrient dynamics, particularly phosphorus (Pi) availability. Despite notable advancements in root research, comprehending belowground processes related to Pi remains a formidable challenge.

To address this gap, we are currently spearheading the development of innovative platforms for visualising root growth, RSA, and rhizosphere interactions at UWA through collaborations with colleagues at UWA's Centre for Microscopy, Characterisation and Analysis (CMCA), and external experts. We are engaged in optimising live scanning techniques utilising X-ray CT. This ongoing pilot study aims to fine-tune various parameters such as pot size, materials, soil density, and segmentation techniques using sophisticated programs like Rootine and deep learning algorithms. These endeavours are geared towards enhancing our capability to visualise and analyse RSA in three dimensions.

Quantifying rhizosphere pH, acid phosphatase activity, and labile Pi content is of paramount importance, albeit challenging. Leveraging optically transparent polyester foils from PreSens along with the VisiSens imaging system, our aim is to visualise rhizosphere pH fluctuations. Additionally, we are conducting soil zymography to visualise acid phosphatase activity and exploring labile Pi visualisation using diffusive gradients in thin films.

Furthermore, we are delving into soil zymography and employing advanced imaging modalities such as NanoSIMS and Focused ion beam scanning electron microscopy (FIB-SEM) to unravel the intricate mechanisms governing microbial communities' activity and Pi dynamics in the rhizosphere. This multifaceted approach will provide invaluable insights into the spatial dynamics of Pi mineralisation and mobilisation, significantly enhancing our understanding of rhizosphere processes.

The development of these cutting-edge imaging platforms promises to revolutionie our understanding of RSA and rhizosphere dynamics, particularly concerning Pi availability. Furthermore, these platforms will serve as invaluable resources for researchers delving into root studies, ultimately contributing to agricultural sustainability and enhanced productivity.

Future endeavours will focus on refining imaging techniques, broadening the application of these platforms to diverse plant species and soil types, and integrating molecular and genomic approaches to decipher underlying mechanisms. Additionally, collaborations with international laboratories and industry partners will facilitate the translation of research findings into practical applications for agriculture and environmental management, thus fostering sustainable solutions for the future.

This research is supported by UWA and the ARC.

Exploring root system architecture and anatomical variability in alfalfa seedlings

Project team: Dr Yinglong Chen[1], Dr Zhi Wang[2] (project leader; wangzhi712@nwafu.edu.cn), Xinya Pan[2], Pengfei Wang[2], Xianwei Wei[2], Jinxin Zhang[2], Professor Bingcheng Xu[2], Professor Gehong Wei[2]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China

Alfalfa (*Medicago sativa* L.) is globally recognised as one of the most vital fodder crops due to its high protein concentration, robust biological nitrogen fixation capacity, adaptability, and prolific yield. The burgeoning demand for alfalfa, particularly in developing countries like China, is spurred by the rapid expansion of the livestock industry. However, the growth of alfalfa is substantially hindered by abiotic stressors, notably nutrient deficiencies and drought stress. The root system plays a pivotal role in nutrient acquisition and stress adaptation. Selecting alfalfa genotypes with desirable root traits is imperative to enhance resource absorption efficiency and environmental stress tolerance.

In this collaborative project, we aimed to assess the variability in root system architecture and anatomical features (42 root traits evaluated), nitrogen (N), and phosphorus (P) uptake among 53 alfalfa genotypes during the seedling stage (42 days after sowing) using a visual rhizobox system. Our study showed that, among the measured traits, 21 root traits, along with N and P uptake, exhibited substantial genotypic variation. Local root morphological and anatomical traits displayed greater variability than global root traits. Principal component analysis revealed that 23 traits with cultivars (CV) greater than or equal to 0.25 contributed to six principal components, collectively explaining 88 per cent of the overall genotypic variation. Root traits such as total root length, number of root tips, maximal root depth, total stele area, and xylem vessel area showed positive correlations with shoot and root dry mass as well as N and P uptake.

The identified root traits associated with biomass production and nutrient uptake hold promise for the breeding of alfalfa genotypes with enhanced resource absorption efficiency and stress tolerance. Further validation of these traits throughout the growth period in field conditions is warranted to ascertain their utility in alfalfa breeding programs. Future research should also explore root trait interactions with other agronomic traits. Additionally, incorporating genomic approaches could expedite the selection of superior alfalfa genotypes with enhanced root traits and overall adaptability. Such efforts are crucial for meeting the escalating demand for alfalfa and ensuring sustainable forage production in the face of changing environmental conditions.

This research is supported by the Ordos City Science and Technology Planning Project, Forestry Science and Technology Innovation of Shaanxi Province, National Natural Science Foundation of China, The Youth Project of the Natural Science Basic Research Program of Shaanxi Province, and the ARC.

Plants and root systems of four different genotypes of alfalfa grew in soil-filled rhizoboxes showing variation in both shoot and root growth.

Distribution characteristics and correlation of macro- and microplastics under long-term plastic mulching in northwest China

Project team: Professor Xining Zhao[2] (project leader; xiningz@aliyun.com), Dr Junhao Cao[3], Professor Xiaodong Gao[2], Dr Qi Hu[3], Dr Changjian Li[2], Associate Professor Xiaolin Song[3], Professor Yaohui Cai[2], Hackett Professor Kadambot Siddique[1]

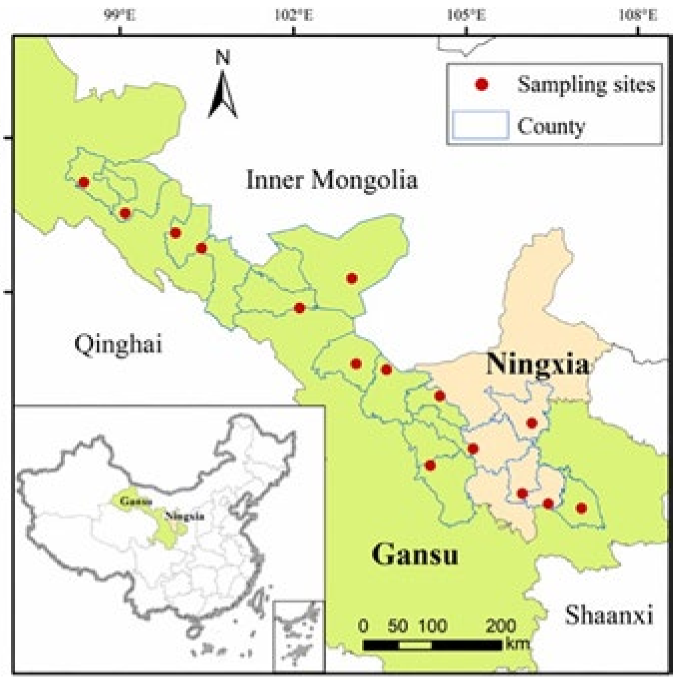
Collaborating organisations: [1]UWA; [2]Chinese Academy of Sciences and Ministry of Water Resources, China; [3]Northwest A&F University, China

Plastic film mulching applications can lead to high macroplastics (MaPs) and microplastics (MPs) concentrations in soils, adversely affecting soil health and crop production. However, the large-scale distribution pattern and correlation between MaPs and MPs presence in soils remain unknown.

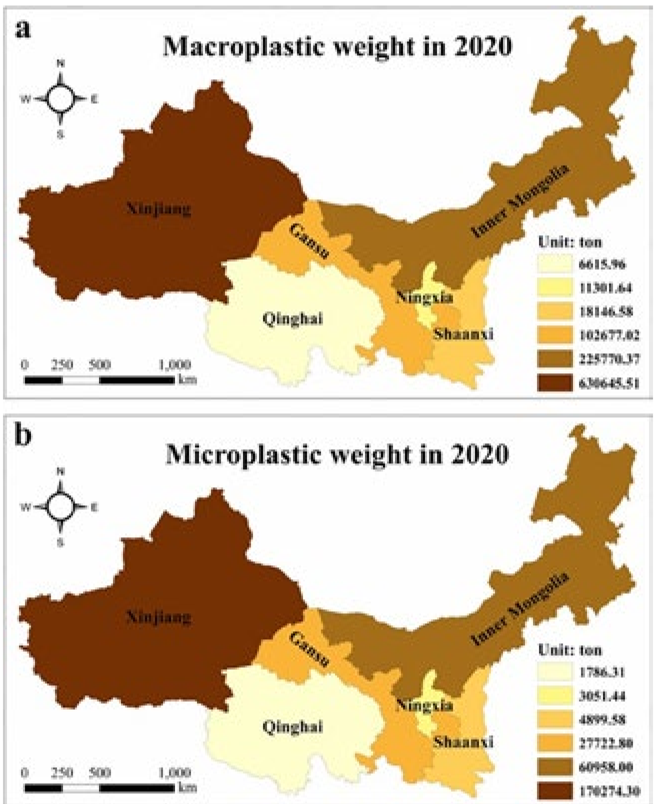
In this study, we selected 60 maize fields from 15 counties in northwest China to investigate the distribution and correlation of MaPs and MPs at different soil depths (0–10, 10–20, 20–30, 30–40cm) and different plastic mulching years (5, 10, 15, 20 years). The results showed that MaPs are mainly concentrated at 0–10cm soil depth, while MPs are distributed predominantly at 10–20cm soil depth. Most MaP particles (45 per cent of the total number) were within the 1–5cm² size range, whereas MP particles in the 0.1–1 mm size range dominated (48 per cent). An increase in MaP weight by 1.00kg ha−1 increased MP weight by 0.27 kg ha−1, and an increase in MaP number by 1.00 × 104 pieces ha−1 increased MP weight by 0.90kg ha−1. An increase in MP weight by 1.00kg ha−1 increased MP number by 5.43 × 107 pieces ha−1. Fourier transform infrared spectroscopy and scanning electron microscopy results revealed degradation of the plastic surface, with further fragmentation into smaller particles likely. Based on our findings, we estimated that farmland in northwest China in 2020 contained 1.0 × 106 tons MaP and 2.7 × 105 tons MP.

The severe MaP and MP pollution in China's farmland requires improved recycling efficiencies and management practices of plastic film to ensure food security and sustainable agricultural development.

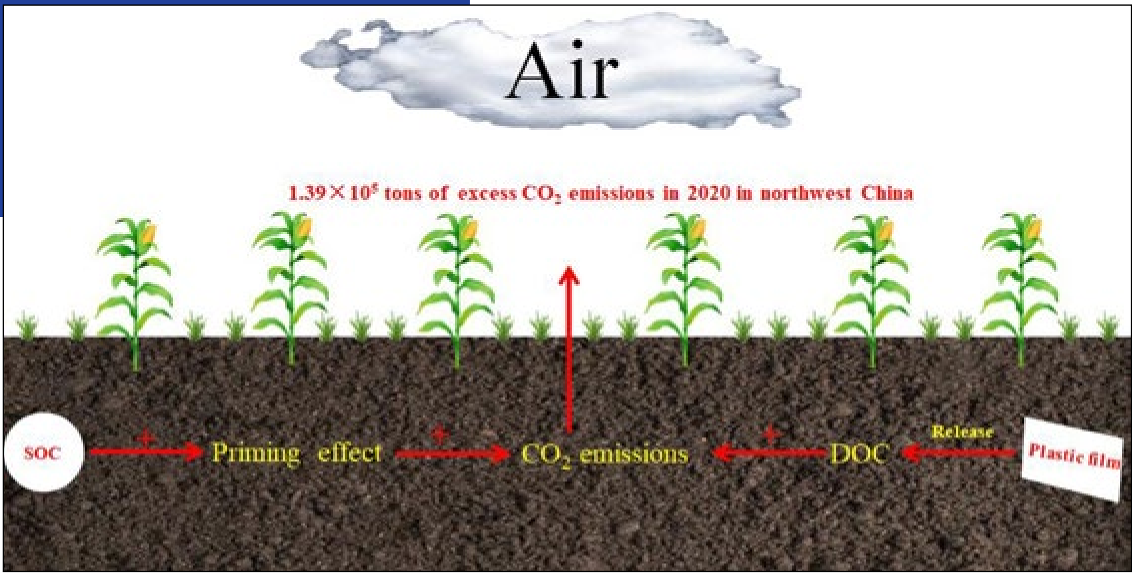
This research is supported by the National Key Research and Development Program, National Natural Science Foundation of China, and Innovation Ability Supporting Program of Shaanxi Province.



Map of the spatial distribution of sampling points for macroplastic and microplastic quantification in maize fields in 15 selected counties in China.



Estimated macroplastic (a) and microplastic (b) loads in six provinces of northwest China in 2020. This estimated distribution was based on the recovery rate, degradation rate and water erosion of plastic film.



The graphical abstract for the study.

Agricultural soil plastic as a hidden carbon source stimulates microbial activity and increases carbon dioxide emissions

Project team: Professor Xining Zhao[2] (project leader; xiningz@aliyun.com), Dr Junhao Cao[3], Dr Changjian Li[2], Professor Xiaodong Gao[2], Professor Yaohui Cai[2], Associate Professor Xiaolin Song[3], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Chinese Academy of Sciences and Ministry of Water Resources, China; [3]Northwest A&F University, China

The ability of plastic in soil to increase CO_2 emissions led the research team to hypothesise that:

1) In plastic soil, the plastic continuously releases DOC and can be used for microbial growth,
2) Biomass growth accelerates DOC leaching from plastic and soil organic carbon (SOC), increasing CO_2 emissions from plastic soil, and
3) Once BP film completely replaces PE film, the large amounts of CO_2 emissions from BP plastic soil.

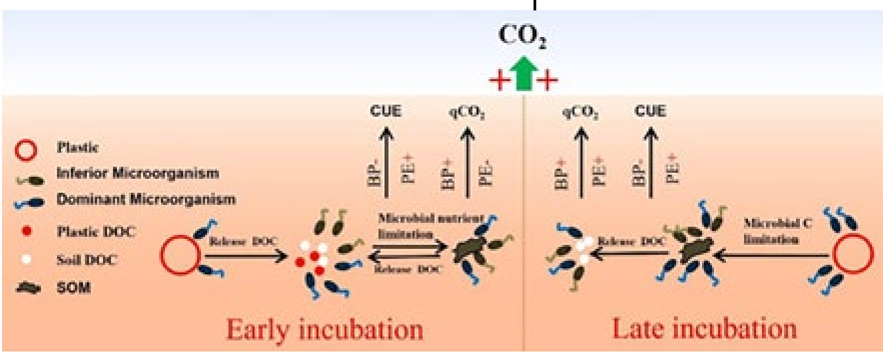
To verify these hypotheses, we selected three soil environments, two plastic materials (polyethylene [PE] and biodegradable plastic [BP]) two plastic sizes (MPs and macroplastic), and 19 treatments, comprising 190 individual incubations, to explore the potential of DOC leaching from plastic and its effect on CO_2 emissions. Based on the results of this experimental study, we estimated the excess CO_2 emissions from PE plastic soil and BP soil (assume BP film replaces PE film) of China. This systematic study will help understand the factors and mechanisms of DOC leaching after plastic (PE and BP) enters the soil, and the potential mechanisms controlling CO_2 production will help improve the estimates and predict future plastic soil CO_2 emissions.

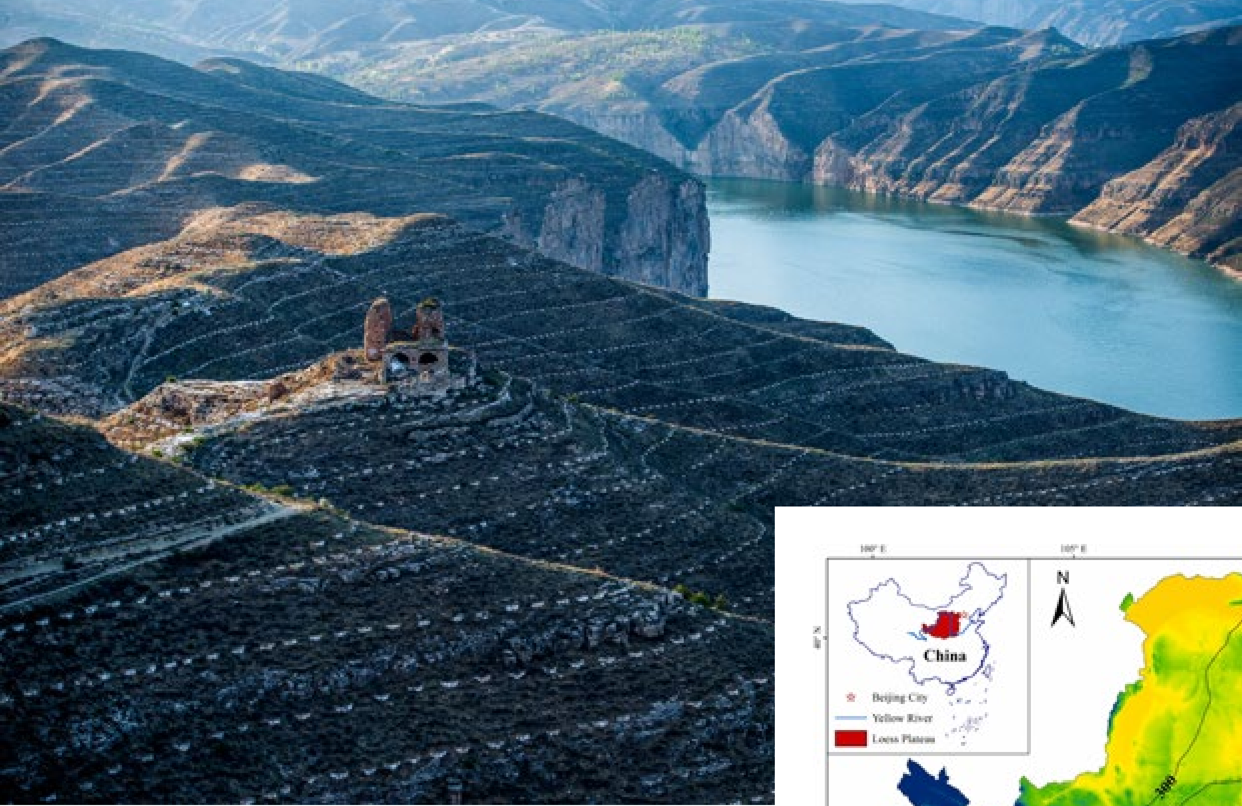
Leaching behaviours of DOC from PE and BP plastic polymers in soil were examined and the effect of plastic DOC on soil carbon cycling was explored. Through meta-analysis and model simulation, the residual PE plastic film content and the excess CO_2 emissions in the six northwest provinces of China were estimated. The following main conclusions can be drawn based on the results of this study.

- The law of DOC released from plastic in soil is that of the most DOC is released instantaneously, and then gradually decreases over time. The DOC released from plastic can be quickly used by microorganisms, participates in soil C cycling, and increases CO_2 emissions.
- The release of plastic DOC in soil is influenced by many factors, including soil moisture content and microorganisms, while the presence of SOC slowed the release of plastic DOC.
- The meta-analysis showed that the total effect size of 1g plastic on soil excess CO_2 emissions was 38.22 mg-C. The soil excess CO_2 emissions was influenced by PE plastic concentration and soil type.
- The residual PE plastic film weight was 9.95×10^5 tons, and the excess CO_2 emissions to from farmland soils was 1.39×10^5 tons in the six northwest provinces of China in 2020.

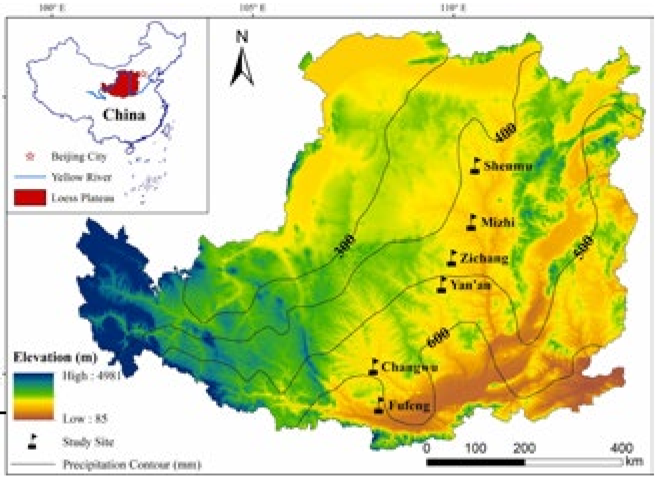
This research is supported by the National Key Research and Development Program, National Natural Science Foundation of China, and Innovation Ability Supporting Program of Shaanxi Province.

Regulation mechanism of dissolved organic carbon (DOC) released from plastic on carbon dioxide emissions through microbial metabolism limitations.





The Loess Plateau landscape in China. Credit: Qing Yi



Location of sampling sites on the Loess Plateau of China.

Divergent responses of deep SOC sequestration to large-scale revegetation on China's Loess Plateau

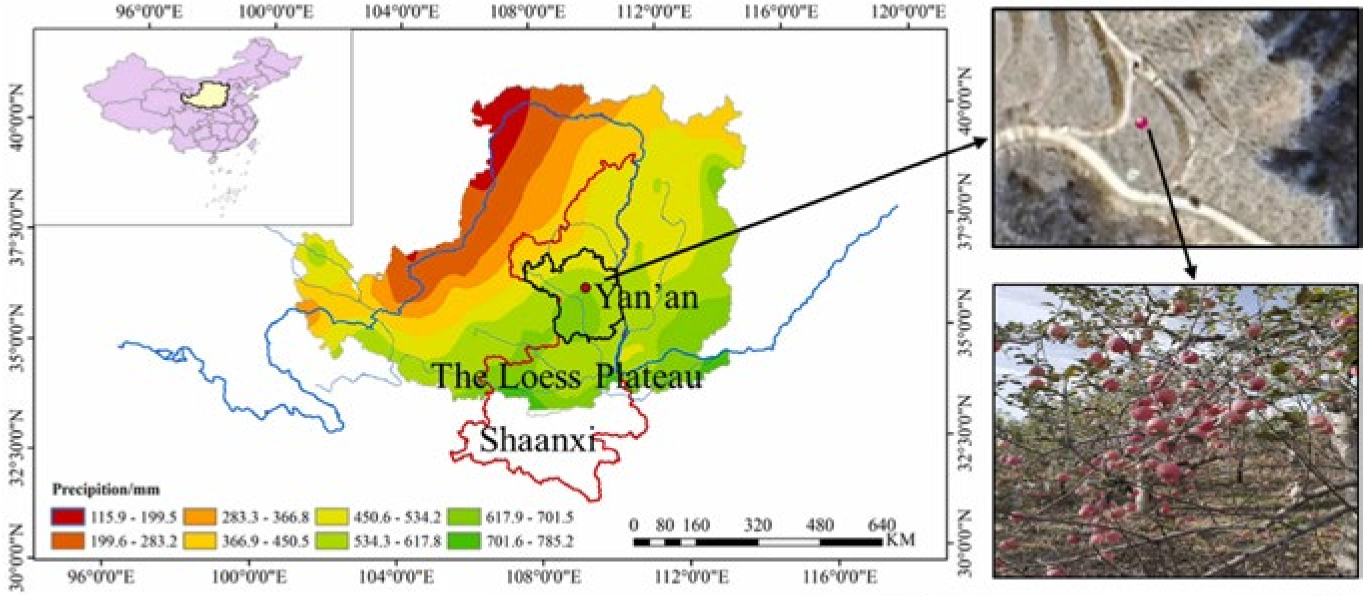
Project team: Associate Professor Min Yang[2], Professor Xiaodong Gao[2], (project leader; gao_xiaodong@nwafu.edu.cn), Dr Shaofei Wang[2], Dr Qi Hu[2], Dr Juanjuan Song[2], Nanfang Ma[3], Xiaolin Song[2], Dr Pute Wu[2,3], Professor Xining Zhao[2,3], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]Chinese Academy of Sciences and Ministry of Water Resources, China

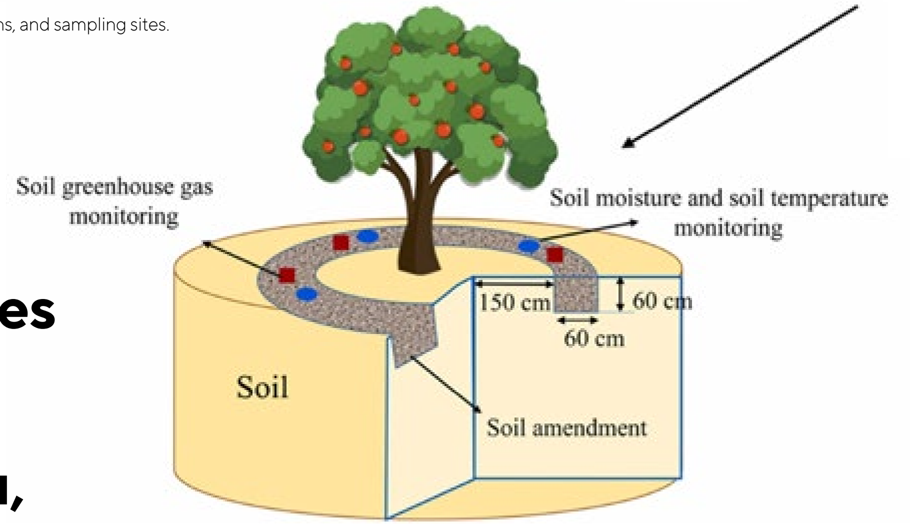
Dryland revegetation can mitigate land degradation, increase vegetation coverage and terrestrial carbon (C) sinks, and substantially decrease soil water storage. However, variation in soil organic carbon (SOC) sequestration with precipitation under large-scale ecological restoration is unclear, and the trade-off between SOC sequestration and water consumption under different vegetation types remain controversial, particularly in deep soils.

This study investigated SOC storage (SOCS) and soil water storage (SWS) in 0–1000cm profiles under various vegetation types (woodland, shrubland, grassland, and farmland) along a precipitation gradient from 406mm to 606mm on China's Loess Plateau. The four vegetation types exhibited similar trends in the spatial distribution of SOCS and SWS, significantly increasing as mean annual precipitation (MAP) increased, except for SWS in shrubland. In contrast, deep SOC sequestration and water deficit effects varied with vegetation type and MAP. Specifically, ΔSOCS (SOCS difference between restored vegetation and farmland) of woodland significantly decreased with increasing MAP, whereas no significant relationship occurred for shrubland and grassland; significant positive and negative linear correlations occurred between ΔSWS (SWS difference between restored vegetation and farmland) and MAP for woodland and shrubland, respectively, with no apparent relationship for grassland. Moreover, the three restored vegetation had positive correlations between ΔSOCS and ΔSWS in deep soils. Woodland had the highest SOC sequestration efficiency (ΔSOCS/ΔSWS) but also caused the most severe soil water deficit, while grassland had the lowest C and water effect. Therefore, shrublands are better for revegetation in semiarid regions, with relatively lower soil water deficit than woodland and higher SOC sequestration effect than grassland; multispecies forest plantations dominated by *R. pseudoacacia* may be more suitable than single-species plantations in semihumid regions. These findings highlight the SOC sequestration potential of deep soils and offer insights into dryland revegetation.

This research is supported by National Natural Science Foundation of China, Shaanxi Key Research and Development Program, Natural Science Basic Research Program of Shaanxi, Cyrus Tang Foundation, and Chinese Universities Scientific Fund.



Location of the experimental area, soil amendment additions, and sampling sites.



Greenhouse gas emission responses to different soil amendments on the Loess Plateau, China

Project team: Dr Pute Wu[2,3] (project leader; gjzwpt@vip.sina.com), Dr Yanhong Ding[2], Dr Changjian Li[2,3], Dr Zhao Li[2], Associate Professor Shuai Liu[2], Adjunct Associate Professor Yufeng Zou[1,2], Professor Xiaodong Gao[2,3], Dr Yaohui Cai[2,3], Professor Xining Zhao[2], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]Chinese Academy of Sciences and Ministry of Water Resources, China

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the main greenhouse gases (GHGs) in the atmosphere. According to Rama et al. (2022), agricultural operations produce over 12 per cent of GHG emissions, with N_2O and CH_4 concentrations accounting for 60 per cent and 50 per cent of the total GHGs produced by human agricultural activities, respectively. Therefore, identifying an innovative approach to the mitigation of GHG emissions is critical for alleviating global warming and enhancing C sequestration in farmland.

In this study, soil amendments increased soil moisture, pH, soil organic matter (SOM), TN, NO_3^--N, and NH_4^+-N in two consecutive years (except NH_4^+-N in 2020). The soil amendments decreased C-cycling enzyme activity (including BG, CBH, BX, cellulase and sucrase) but increased N-cycling enzyme activity (NAG). However, the soil amendments had little effect on microbial abundance or diversity, affecting microbial strains related to the C and N cycles, thus affecting GHG emissions. The soil amendments reduced soil CO_2 emissions in both years by changing soil physicochemical properties, and soil enzyme and microbial activities. N_2O emissions increased in the first year but then decreased gradually. Overall, the soil amendments mitigated GHG emissions and global warming in the long term.

In general, soil amendment alone (biochar or plant growth-promoting rhizobacteria [PGPR]) had a limited effect on improving SOM and soil moisture and reducing GHG emission on the Loess Plateau. Biological (NAG, β-xylosidase, cellobiohydrolase, *Proteobacteria*, *Mortierellomycota* and *Acidobacteriota*) and abiotic (SOM and available phosphorus [AP]) factors significantly affected GHG emissions. In addition, the interactions between C and N substrates, AP in microbially mediated, and soil microbial and enzyme activities play major roles in regulating GHG emissions. Therefore, we recommend combining biochar and PGPR applications to change the soil's biological and abiotic environment and mitigate GHG emissions. Thus, future work should evaluate mixed soil amendments, rather than single soil amendments, in long-term trials to test the causal relationships between soil amendments, soil quality and GHG emissions.

This research is supported by the National Key Research and Development Program of China, National Natural Science Foundation of China, Key Research and Development Program of Shaanxi Province, and the Cyrus Tang Foundation.

An artist's impression of a Mars living environment. Credit: Bruce Moffett

UWA International Space Centre: Plants in Space

Project team: Professor Harvey Millar[1] (UWA project leader; harvey.millar@uwa.edu.au), Professor Ryan Lister[1,2], Professor Ian Small[1], Dr James Lloyd[1], Dr Bhagya Dissanayake[1], Dr Hui Cao[1], Dr Samalka Wijeweera[1], Samantha Harvie[1]

Collaborating organisations: [1]UWA; [2]Harry Perkins Institute of Medical Research

The UWA International Space Centre's Plants in Space capability launched in 2022 and is led by the University of Adelaide. In early 2023, the UWA node of the program was awarded additional funding to support space exploration through autonomous agriculture. Among 2023 highlights, Dr James Lloyd won a Mid Career Research Foundation Award. In 2023 the ARC Centre of Excellence in Plants for Space led by the University of Adelaide and including UWA researchers was awarded and is scheduled to begin in 2024 for a seven year term.

The UWA Plants in Space team are focused on the following priorities:

- Plant respiration modification to maximise growth and minimise CO_2 release,
- Plant growth habitat design for the International Space Station and other off-earth missions,
- Plant protein production system design and optimisation,
- Understanding plant cell responses to altered environments and growth conditions, and
- Engineering plant gene activity through programmable genetic computation for optimised plant performance and modified function.

In a project funded separately by the UK Space Agency to the UK company Vertical Future and collaborators, the UWA team are using high CO_2 simulated plant growth chambers, hydroponic growth systems and camera systems to monitor how algorithms used to predict plant growth would perform under high CO_2 conditions expected in space stations. The facility is being designed for the Axiom Station, a series of modules for human habitation that will be launched into orbit in stages from 2025 and will replace the International Space Station.

'Autonomous agriculture technologies' to grow plants as food in space has the potential to inform and innovate Earth-bound agricultural practices. These include applications for vertical farming, protected cropping and other intensive horticulture or seedling raising systems. Additionally, remote monitoring of plant production can be important for deployment of food growing systems in remote environments on Earth, in which local production is more desirable than the transport logistics to supply needs.

This research is supported by UWA, the University of Adelaide, Australian Government, ARC, UK Space Agency's International Bilateral Fund, Vertical Future, and additional funding and in-kind support from 38 partner organisations to the ARC Centre of Excellence in Plants for Space.

A head of lettuce in a hydroponic growth system.

Root morphology and plant growth of Macadamia integrifolia under different N treatment.

Professor Patrick Finnegan and Dr Yupin Li demonstrate macadamia roots as part of their hydroponic study.

Determining the impact of different forms of nitrogen on macadamia growth and yield

Project team: Dr Yupin Li[1,2] (project leader; yupin.li@uwa.edu.au), Professor Patrick Finnegan[1], Emeritus Professor Hans Lambers[1]

Collaborating organisations: [1]UWA; [2]Yunnan Agricultural University, China

Macadamia spp. belong to family Proteaceae and originated from rainforests along the east coast of Australia. Due to the flavour and nutritional value of the edible nuts from *M. integrifolia* and *M. tetraphylla*, macadamia has tremendous commercial value. Outside Australia, many other countries grow macadamia commercially, including China, United States, Brazil and South Africa. In fact, China now has the largest macadamia growing area in the world.

Nitrogen is one of the three major nutritional elements indispensable for plant growth and development. Nitrogen absorption and assimilation mechanism have become the focus of much research. However, the demand and preference of nitrogen source for macadamia remains unclear.

In the context of sustainable agriculture, improving resource utilisation efficiency is a key concern. Farmers often have an imperfect knowledge of science-based cultivation practices and environmental protection awareness. This underlies excessive application of fertilisers and pesticides in macadamia plantations, which has led to nutritional imbalance and disease susceptibility in macadamia trees. These outcomes have become key limiting factors restricting the sustainable development of the macadamia industry in many parts of the world.

This project aims to identify forms and amounts of nitrogen fertilisers that best match the needs of macadamia. Together with an investigation on the impact of nitrogen forms and amounts on the dynamics and functional attributes of the soil microbial community in plantations, this research will help clarify the nitrogen fertilisation practices that are best suited for macadamia plantations.

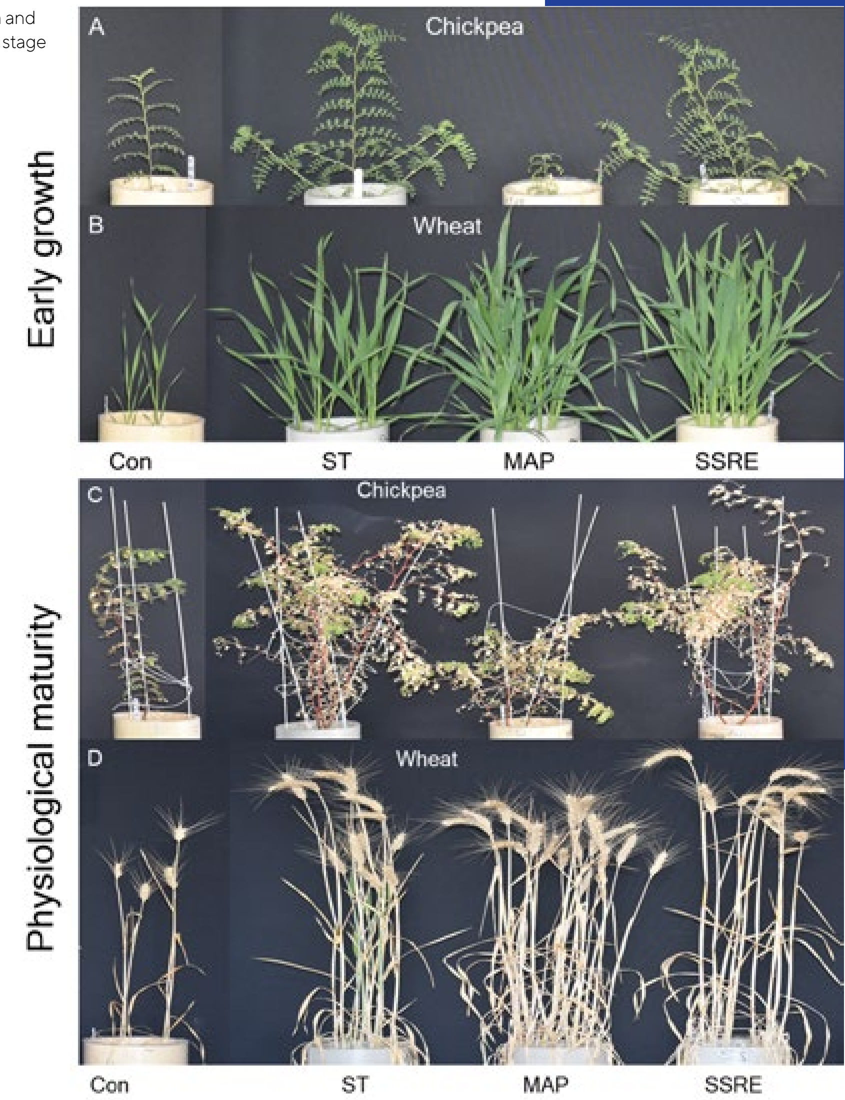
For the UWA experiments, which began in June 2023, macadamia plants were treated with various amounts of ammonium or nitrate fertilisation in hydroponics. There are significant differences in root system and overall plant growth between the two forms of nitrogen. Under nitrate treatment, plant root length is significantly greater than that under ammonium treatment; intermittent ammonium supply promoted the growth of first-level lateral roots, while a constant ammonium supply inhibited the growth of lateral roots.

This study will determine the impact of different forms of nitrogen on macadamia growth and yield using both greenhouse and plantation experiments, as well as the impact of nitrogen form on soil microbial community structure and function.

Practically, the results from this study will provide theoretical basis for optimised fertilisation of macadamia, thus increasing the sustainability of industrial development. Academically, this study combines aspects of microbiology, bioinformatics, soil science and ecology, indeed a multi-disciplinary cross-integration. The results will lay the foundation for further research on the co-evolution among soil microorganisms, plants and the ecological environment.

This research is supported by UWA and Yunnan Agricultural University, China.

Visual representation of chickpea and wheat growth at the early growth stage and physiological maturity.



Chickpea is more efficient to access phosphorus from wastewater-recovered struvite than wheat

Project team: Manish Sharma[1], Dr Sasha Jenkins[1] (project leader; sasha.jenkins@uwa.edu.au), Hackett Professor Kadambot Siddique[1], Professor Megan Ryan[1], Dr Jiayin Pang[1], Dr Bede Mickan[1,2]

Collaborating organisations: [1]UWA; [2]Richro; Australian Government; Water Corporation Perth; The ARC Training Centre for Transformation of Australia's Biosolids Resource

Phosphorus (P) recycling, recovery and reuse from wastewater offer a promising approach to mitigate eutrophication and reduce reliance on phosphate rock reserve. The study investigated the effectiveness of struvite as a sustainable P source compared to conventional P fertilisers on chickpea and wheat growth, P uptake and soil microbial communities.

Three P sources were used: struvite (ST), mono-ammonium phosphate (MAP) and Super SR Extra (SSRE). Plants were grown in P-deficient soil in a temperature-controlled glasshouse environment and harvested during the early growth stage and at physiological maturity. Phosphorus leaching behaviour from ST, MAP and SSRE was assessed in a second set of pots.

At the early growth stage, ST and SSRE produced similar chickpea shoot dry weights (DW), which were approximately 80 per cent higher than for MAP. Conversely, wheat shoot DW for ST was half of that for MAP and SSRE. Moreover, ST and SSRE produced similar shoot P contents for chickpea, which were approximately 60 per cent higher than for MAP, whereas for wheat, ST had 76 per cent and 66 per cent lower shoot P contents than for MAP and SSRE, respectively. Struvite produced 6.4 and 1.6-fold more rhizosheath carboxylates for chickpea than MAP and SSRE, while wheat had low rhizosheath carboxylates that differed little among treatments.

Chickpea grain yield for ST was 46 per cent and 15 per cent higher than MAP and SSRE, respectively, whereas wheat grain yield for ST and SSRE was approximately 30 per cent lower than MAP. Struvite had extremely low P leaching compared to MAP and SSRE and did not alter soil bacterial community structure. Overall, wastewater-recovered ST effectively supplied P to chickpea and wheat, with a more pronounced benefit observed in chickpea. Therefore, ST holds promise as a sustainable P source for agricultural fertilisation.

This research is supported by UWA, the Australian Government's National Landcare Program, Smart Farming Partnerships and partners, The AW Howard Memorial Trust Tim Healy Scholarship, and the ARC Training Centre for Transformation of Australia's Biosolids Resource.

Chickpea drought experiment set-up at Nanaji Deshmukh Plant Phenomics Centre in New Delhi, India.

Unlocking drought tolerance in chickpea genotypes: Integrating image-based screening with physiological insights

Project team: Sneha Priya Pappula Reddy[1], Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au), Professor Harvey Millar[1], Dr Jiayin Pang[1], Dr Bharadwaj Chellapilla[2], Professor Madan Pal Singh[1,2], Dr Sudhir Kumar[2]

Collaborating organisations: [1]UWA; [2]ICAR - Indian Agricultural Research Institute, India

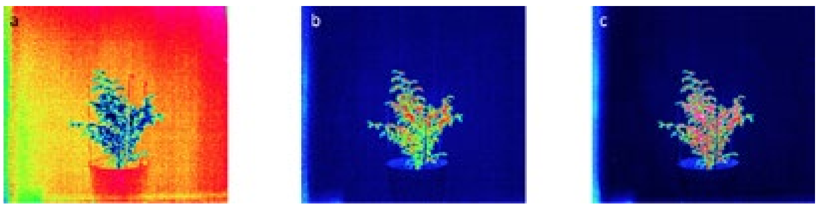
Chickpea (*Cicer arietinum* L.) is a cool-season leguminous pulse crop cultivated globally, particularly in Afro-Asian regions with abundant nutritional benefits and superior protein quality, yet the escalating impact of global climate change, particularly terminal drought stress, significantly threatens its production, leading to widespread crop yield loss of up to 70 per cent. Reduction in flower and pod numbers and increased flower and pod abortion rates have been evidenced by terminal drought, which is the reason for the drastic yield decrease in chickpea. Conventional breeding techniques employed for screening drought-tolerant chickpea lines are labour-intensive and time-consuming.

High-throughput phenotyping (HTP) has emerged as a promising solution, offering fast, precise, and automated data collection methods to expedite the development of drought-adapted cultivars. It can rapidly assess numerous plant growth and yield prediction traits, significantly reducing the time required for data collection and analysis. Modern high-throughput imaging technologies can monitor plant physiological changes to drought stress non-destructively, serving as early indicators of drought stress to identify drought-resistant cultivars. Further integration of HTP data with quantitative trait loci data can be useful in breeding programs for precisely selecting abiotic-stress-tolerant lines. HTP mitigates the need for extensive field trials and resource-intensive cultivation practices by focusing on promising genotypes early in breeding. When integrated with genomic information, it becomes a powerful tool for breeding programs through genomic selection.

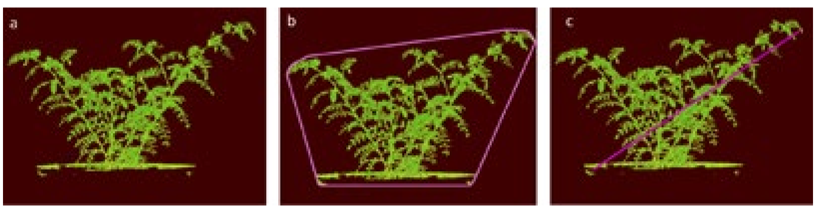
The specific objectives of this study are:

i) To assess the differences between well-watered and drought-stressed treatments using image-based and manually recorded traits,
ii) To evaluate the variable responses of chickpea genotypes to terminal drought in terms of yield, biomass, growth, and photosynthetic traits recorded using digital imaging techniques and manual recording, and
iii) The comparison of the potential of an HTP platform to a traditional recording method for screening chickpea genotypes under terminal drought stress.

This research is supported by the UWA Scholarship for International Research Fees and University Postgraduate Award, Australia-India Strategic Research Fund, and Department of Biotechnology, Government of India.



Red, green, and blue images of a chickpea genotype indicating (a) Projected shoot area, (b) Convex hull area and, (c) Caliper length.



Hyperspectral images of chickpea genotype at (a) 1.0, (b) 0.6 and (c) 0.4 fraction of transpirable soil water.

Progress on chickpea plants during a team visit to the glasshouse.

Tightening the phosphorus cycle for grain legumes

Project team: Dr Jiayin Pang[1] (project leader; jiayin.pang@uwa.edu.au), Professor Hans Lambers[1], Hackett Professor Kadambot Siddique[1], Associate Professor Peta Clode[1], Professor Rajeev Varshney[2], Huaikang Jing[1], Xiaolong Feng[1], Chuangwei Fang[1]

Collaborating organisations: [1]UWA; [2]Murdoch University; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) China Agricultural University, China; Shenyang Agricultural University, China; Mingenew Irwin Group

Phosphorus deficiency is a major constraint for crop production. Phosphorus deficiency is currently mitigated by applying large amounts of phosphorus fertiliser, but this practice is inefficient due to phosphorus immobilisation and runoff. Moreover, rock phosphate, one of the cornerstones of modern agriculture, is a non-renewable resource, with prices expected to rise as it becomes scarcer. Therefore, enhancing the phosphorus-use efficiency in grain legume crops is essential for long-term agricultural sustainability. Since phosphorus removal via grain is a major driver of the global phosphorus cycle, one effective strategy is to reduce phosphorus concentration in seeds which can reduce phosphorus export and decrease the demand for fertiliser.

Grain legumes, such as chickpea, soybean and peanut, provide substantial health and nutritional benefits, and also lead to significant advantages for sustainable cropping systems. In Australia, chickpea is the largest pulse crop, cultivated on more than 0.7 million ha.

A large-scale glasshouse experiment was undertaken at UWA in 2023, using a unique chickpea reference set of 275 genotypes. This set included landraces, advanced breeding lines, cultivars and wild relatives with diverse genetic background. The study aimed to assess the genotypic variation in seed phosphorus and phytate concentrations among those genotypes under low phosphorus conditions, as well as phosphorus remobilisation from vegetative tissues to seeds. Significant genotypic variation in both phosphorus remobilisation and seed phosphorus levels were found among 275 genotypes. All phenotyping data will be linked with genome sequence data through a collaboration with Murdoch University using genome-wide association mapping to identify molecular markers associated with phosphorus translocation from vegetative tissues to seeds, and seed phosphorus accumulation.

Identifying chickpea genotypes with low seed phosphorus and phytate concentration will reduce the need for phosphorus fertilisers, improve human and livestock nutrition by reducing the binding of micronutrients by phytate, and lessen environmental pollution from phosphorus excretion.

This research is supported by UWA, ARC Linkage Project, Guangzhou Debai AgroTech, Yingkou Magnesite Chemical Ind Group, and China Agricultural University.


A large-scale glasshouse chickpea experiment.

Presenting details of the experiment to UWA glasshouse visitors.

Morphological and physiological traits of soybean (*Glycine max* L.) under low phosphorus and water stress environments

Project team: Mohammad Salim[1,2] (project leader; mohammad.salim@research.uwa.edu.au), Dr Zakaria Solaiman[1], Hackett Professor Kadambot Siddique[1], Dr Yinglong Chen[1]

Collaborating organisations: [1]UWA; [2]Bangladesh Agricultural Research Institute, Bangaldesh

Soybean (*Glycine max* L.) is a widely grown crop worldwide renowned for its rich protein and edible vegetable oil content. However, soybean plants often encounter water stress and P deficiency in many regions. This research shows the pivotal role of root traits in mitigating the effects of climate change on a global scale and advancing agricultural research.

PhD candidate Mohammed Salim with his soybean experiment.

Modifying root architecture is an effective practical approach to developing crops with improved P acquisition capabilities and drought tolerance. Furthermore, plant root morphology is vital in enhancing phosphorus use efficiency (PUE), root exudation, and water-use efficiency in response to P deficiency and water stress. P application mitigates the adverse effects of water stress on plant growth and soybean development.

This thesis discusses the main and interactive effects of P-level, genotype and water stress on plant growth, agronomic, morphological, and physiological traits, seed yield and yield components. Moreover, it characterises root and shoot traits using a semi-hydroponic system and rhizoboxes and validates root trait data from semi-hydroponic experiments into soil-filled rhizoboxes. These findings enhance our understanding of the adverse impacts of individual and combined P and water stress at different soybean growth stages.

This research project enriches our understanding of root system traits, agronomic practices, and morpho-physiological mechanisms related to drought tolerance and low P tolerance in soybeans. Ultimately, this knowledge will guide future breeding efforts to develop high-yielding soybean varieties that can thrive in low P soils and under drought conditions. Furthermore, these insights can potentially benefit other legume plants and crops cultivated in low P soil and drought-prone environments.

This research is supported by UWA and the Bangabandhu Science and Technology Fellowship Trust under the Ministry of Science and Technology from the Bangladesh Government.

PhD candidate Md Shahin Iqbal screening mungbean for salinity tolerance in glasshouse.

Investigating salinity tolerance in mungbean at the vegetative and reproductive stages using genome-wide association studies and genomic selection

Project team: Md Shahin Iqbal[1], Senior Honorary Research Fellow William Erskine[1] (project leader; william.erskine@uwa.edu.au), Dr Lukasz Kotula[2], Dr Al Imran Malik[3]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]International Center for Tropical Agriculture (CIAT-Asia), Laos; World Vegetable Center, Taiwan

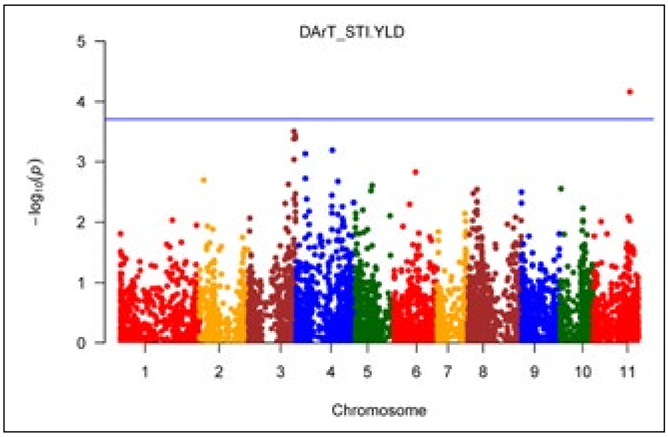
Mungbean is an important grain legume crop widely grown in rice-based farming systems in South and Southeast Asia. Salinity stress has emerged as a severe threat to crop production under different climatic conditions leading towards greater risks for global food security. Mungbean is a relatively salt sensitive species and is affected by varying degrees of soil salinity in Bangladesh, particularly at late crop growth stages. Understanding salinity tolerance associated traits can be used to breed salinity tolerant varieties. Hence, there is a strong need to elucidate the genetic variation, physiological mechanism and genetic basis of salinity tolerance for improving salinity tolerance in mungbean.

Phenotyping mungbean mini-core collection for salinity tolerance.

This study explored the phenotypic and genetic variation within a mungbean mini-core germplasm collection for salinity tolerance at three growth stages: early vegetative, late vegetative and reproductive. Firstly, 292 mungbean were grown at 0mm NaCl (non-saline control) and 75mm NaCl treatments and evaluated at late vegetative stages (45 days after sowing). Further, 130 diverse genotypes selected from phenotypic screening at late vegetative stage were also evaluated for salinity tolerance at both the early vegetative (30 days after sowing) and reproductive stage. Major phenotypic variation was observed in all measured agronomic traits across the growth stages. The variation in reduction of shoot dry mass (per cent of control) varied from 48-90 per cent at early vegetative stage and 45-86 per cent at late vegetative stage. At the reproductive stage, the variation in seed yield reduction varied from 0-100 per cent with a mean of 45 per cent.

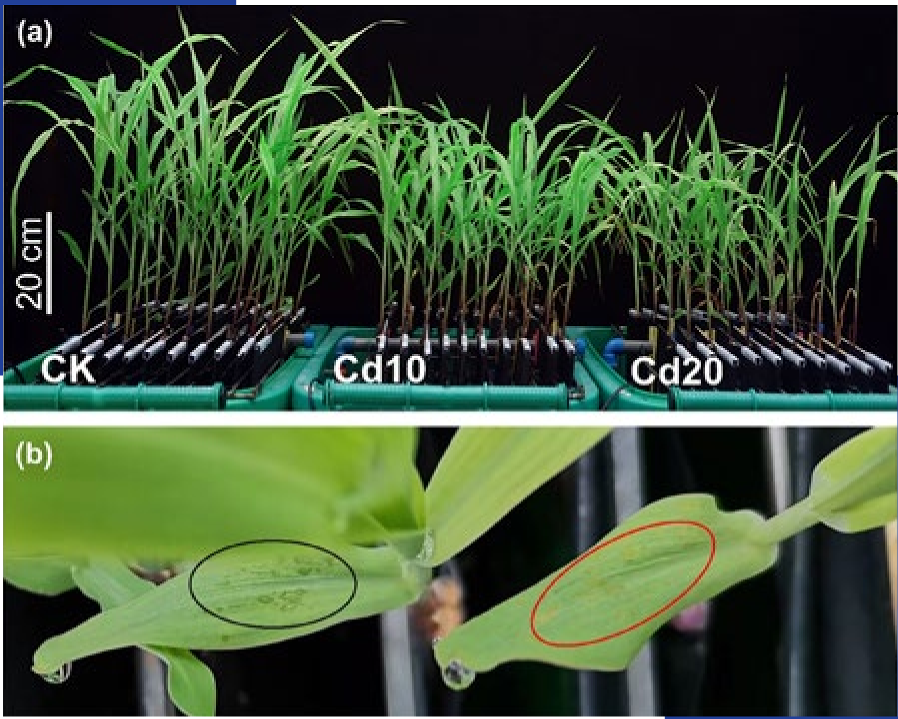
The collection was genotyped in two ways: Using low density 5991 SNPs from DArT sequencing and high density 198474 SNPs from Illumina whole genome resequencing (WGRS-data from World Vegetable Center). Genome-wide association studies (GWAS) revealed a total of 58 significant SNPs. Compared to using DArTseq SNPs, the application of the genomic selection model using WGRS SNPs did not significantly increase the prediction accuracy of the six traits at the late vegetative stage.

The markers identified in the present study are useful for marker-assisted selection in breeding salt-tolerant mungbean following their validation. This increased understanding of morpho-physiology and genetics of salt tolerance in mungbean will guide legume breeders to improve the salt tolerance and climate resilience of legumes such as mungbean.



Manhattan plot showing significant marker-trait association of salinity tolerance index of no. of pods/plant or seed yield. The x-axis indicates the SNP location along the 11 mungbean chromosomes, while the y-axis represents −log10(p) for the p-value of the marker-trait association. The blue horizontal line denotes the 5 per cent Bonferroni-corrected threshold.

This research is supported by UWA, the Australian Centre for International Agricultural Research (ACIAR), and the John Allwright Fellowship Award.



Maize plants grown in the semi-hydroponic system with nutrient amended with Cd (0,10, 20 μmol/L) (upper) and symptoms of Cd poisoning in leaves (lower).

Cadmium accumulation and tolerance in maize genotypes

Project team: Dr Yinglong Chen[1] (project leader; yinglong.chen@uwa.edu.au), Tingting An[2], Qiqiang Kuang[2], Yujie Wu[2], Yamin Gao[2], Associate Professor Yi Zhang[2], Professor Bingcheng Xu[2], Professor Suiqi Zhang[2], Professor Xiping Deng[2], Professor Min Yu[3], Dr Bede Mickan[1]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]Foshan University, China

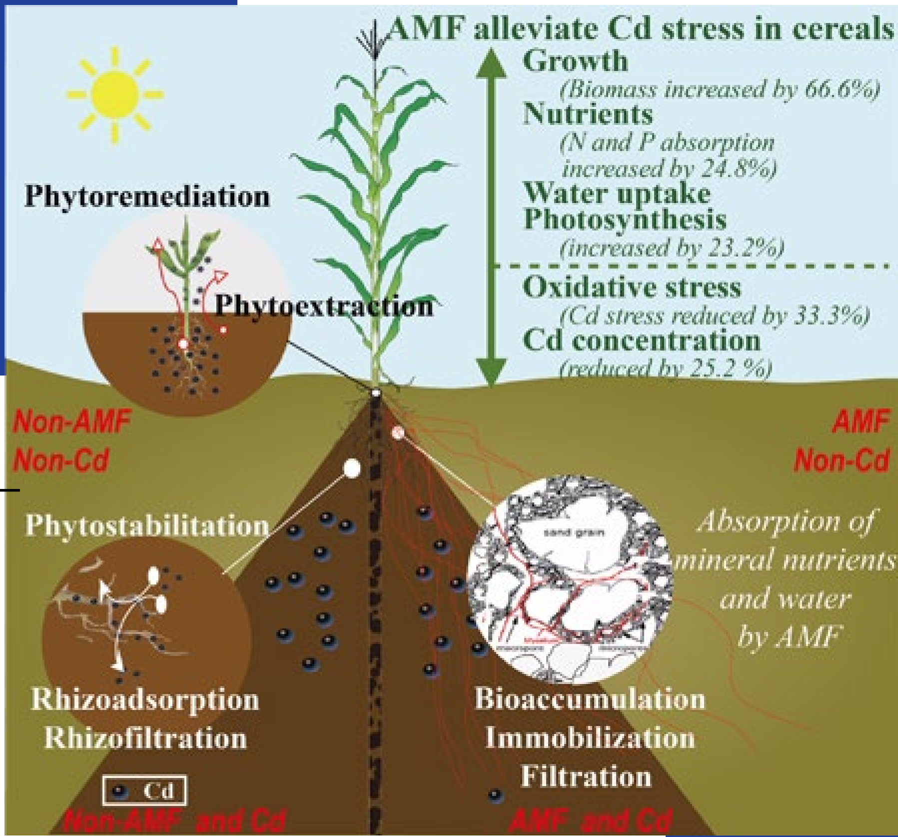
Cadmium (Cd) pollution poses significant threats to both plant health and human well-being. Maize (*Zea mays* L.) genotypes exhibit variability in their ability to accumulate and tolerate Cd. This study aimed to investigate variations in Cd accumulation and tolerance among four maize genotypes with distinct root morphologies.

Four maize genotypes were cultivated in a semi-hydroponic system with three Cd concentrations (0, 10, 20 μmol/L). After 39 days of transplanting, the effects of Cd on plant growth and physiology were assessed. Root characteristics, Cd accumulation, and tolerance mechanisms were evaluated. Under Cd treatment, root characteristics were positively correlated with root Cd accumulation and the bioconcentration factor. Genotypes Shengrui999 and Zhengdan958 exhibited higher total Cd content than Xundan29 and Zhongke11. Cd toxicity induced membrane degradation of chloroplast mesophyll cells, loosening and swelling of grana lamella, and reduced starch reserves. Shengrui999 and Zhengdan958 showed greater tolerance, attributed to factors such as root biomass, shallower root depth, higher Cd content, accumulation of osmolytes (e.g., soluble protein), antioxidant activities (e.g., catalase), and presence of phytohormone gibberellic acid.

This study establishes a link between root morphology, Cd accumulation, and tolerance in maize plants. The higher Cd accumulation and shallower root system observed in Cd-tolerant genotypes highlight their adaptability to moderate Cd-contaminated environments. These findings provide insights for breeding maize cultivars better suited for Cd-contaminated conditions, contributing to environmental sustainability and food safety.

Future research should focus on elucidating the molecular mechanisms underlying Cd tolerance in maize genotypes with contrasting root morphologies. Additionally, field trials are needed to validate the performance of Cd-tolerant cultivars under real-world Cd-contaminated conditions. Incorporating genomic approaches could further accelerate the breeding of Cd-tolerant maize varieties, ensuring sustainable maize production in Cd-affected areas.

This research is supported by UWA, the National Natural Science Foundation of China, and the ARC.



Arbuscular mycorrhizal fungi mitigate the toxic effects of cadmium in cereal crops, using maize as an example.

Understanding arbuscular mycorrhizal fungi mediated alleviation of cadmium stress in cereals

Project team: Dr Yinglong Chen[1] (project leader; yinglong.chen@uwa.edu.au), Yamin Gao[2], Tingting An[2], Qiqiang Kuang[2], Yujie Wu[2], Shuo Liu[2], Liyan Liang[2], Professor Min Yu[3], Professor Andrew Macrae[4]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]Foshan University, China; [4]Universidade Federal do Rio de Janeiro, Brazil

The symbiotic relationships between crop species and arbuscular mycorrhizal fungi (AMF) play a vital role in enhancing plant health, productivity, and environmental sustainability. Despite their significance, the precise functions of AMF in mitigating cadmium (Cd) stress and remediating Cd-contaminated soils remain incompletely understood. In this report, we present findings from a comprehensive meta-analysis aimed at elucidating the roles of AMF in cereals under Cd stress.

As part of this project, we first conducted a meta-analysis using data extracted from 54 articles published between January 1992 and September 2022. The dataset comprised 7216 data points on mycorrhizal cereals under Cd stress. The effects of AMF on colonisation rate, biomass, physiological parameters, nutritional status, and plant Cd levels were assessed using the logarithmic response ratio (Ln R).

The results revealed that AMF significantly alleviated Cd stress in cereals by 5.14 per cent to 33.6 per cent in greenhouse experiments under controlled conditions. AMF colonisation substantially enhanced crop biomass by 65.7 per cent and promoted the synthesis of photosynthetic pigments by 23.2 per cent. Moreover, AMF inoculation led to significant increases in plant nitrogen (24.8 per cent) and phosphorus (58.4 per cent) uptake, thereby enhancing nutrient acquisition. The presence of AMF resulted in a 25.2 per cent decrease in Cd concentration in plants compared to non-mycorrhizal ones, indicating a dilution effect. Additionally, AMF improved osmotic regulators, such as soluble protein, sugar, and total proline, by 14.8 per cent to 36.0 per cent, while reducing membrane lipid peroxidation product (MDA) levels by 12.9 per cent. Analysis revealed that crop type, soil characteristics, chemical form, and Cd levels were the primary determinants of AMF function in alleviating Cd stress.

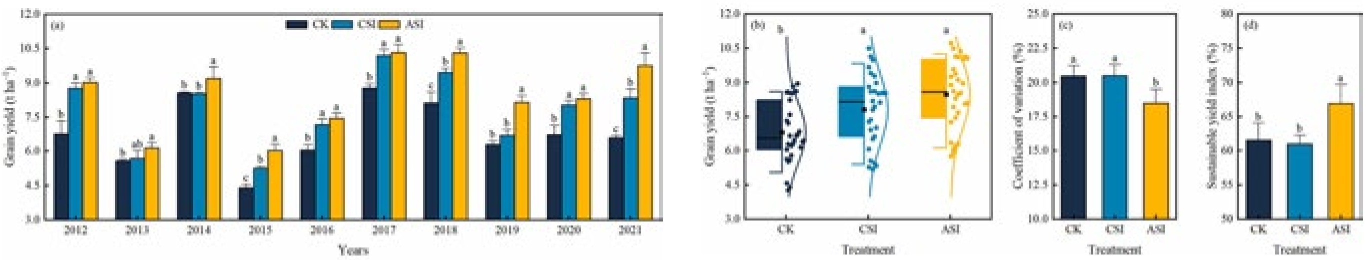
Furthermore, there was a significant interaction between AMF colonisation rate and Cd addition, although the interactive effect was less pronounced compared to the colonisation rate alone.

This meta-analysis underscores the potential of AMF inoculation as a promising strategy for mitigating Cd stress in cereals. By enhancing biomass production, nutrient uptake, and stress tolerance mechanisms, AMF can contribute to sustainable crop production in Cd-contaminated environments.

Followed this, we are investigating the mechanisms underlying AMF-mediated Cd stress alleviation in cereals and exploring the applicability of AMF inoculation in field conditions. Additionally, investigations into the long-term effects of AMF on soil Cd remediation and the sustainability of AMF-based strategies are warranted for developing effective and environmentally friendly approaches to Cd pollution management in agriculture.

This research is supported by UWA, the National Natural Science Foundation of China, and the ARC.

Terraces and agricultural fields on the Loess Plateau of Inner Mongolia, China. Credit: Robert Ford



(a) Grain yield, (b) grain yield distribution, (c) coefficient of variation of grain yield, and (d) sustainable yield index (mean ± SD) from 2012 to 2021 in different treatments (CK, straw removal; CSI, conventional straw incorporation; ASI, ammoniated straw incorporation).

Ammoniated straw incorporation increases maize grain yield while decreasing net greenhouse gas budget on the Loess Plateau, China

Project team: Dr Hao Feng[2,3] (project leader; nercwsi@vip.sina.com), Dr Jinchao Li[2], Dr Yue Li[2], Dr Zhipeng Yang[2], Dr Yanxin Fang[2], Dr Cheng Li[2], Yulong Shi[3], Nanping Lin[3], Dr Qinge Dong[2,3], Dr Naijiang Wang[2], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Chinese Academy of Sciences and Ministry of Water Resources, China; [3]Northwest A&F University, China

Two major concerns of sustainable agriculture are safeguarding food security and attenuating climate warming. Straw incorporation is a widely used field management measure, but issues are associated with its high carbon:nitrogen (C:N) ratio. Ammoniated straw treatments aim to reduce straw C:N ratio; however, studies on the performances of long-term ammoniated straw incorporation on maize grain yield and net greenhouse gas (GHG) budget are still scarce.

We conducted a long-term in situ trial (2012–2021) to estimate the performance of different straw utilisation methods (CK, straw removal; CSI, conventional straw incorporation; ASI, ammoniated straw incorporation) on grain yield, GHG emissions, net ecosystem carbon budget (NECB), net greenhouse gas budget (NGB), and net greenhouse gas intensity (NGHGI) in maize fields. Grain yield was 8.3 per cent and 24.7 per cent greater with ASI than that with CSI and CK, respectively. And ASI had the lowest coefficient of variation for grain yield and the highest sustainable yield index.

However, in comparison with CK, both straw incorporation methods significantly aggravated CO_2 and N_2O emissions, on average, by 101.0 per cent and 107.5 per cent (CSI) and 59.4 per cent and 80.8 per cent (ASI), respectively. The CK, CSI, and ASI obtained average NECB values of 38, 841, and 1556 kg C ha^{-1}, respectively.

The amount of C in soil heterotrophic respiration, roots, extra-root material, and straw input significantly affected NECB. NGB and NGHGI were ranked ASI < CSI < CK, which was attributed primarily to significant changes in NECB, followed by N_2O emissions.

These results suggested that ASI can enhance maize yield and yield stability and reduce net GHG budget on the Loess Plateau.

This research is supported by the National Key R&D Program of China, China Postdoctoral Science Foundation, National Natural Science Foundation of China, and the 111 Project.

Mitigating greenhouse gas emissions by replacing inorganic fertiliser with organic fertiliser in wheat–maize rotation systems in China

Project team: Professor Shufang Wu[2] (project leader; wsfjs@163.com), Dr Yajin Hu[2,3], Donghao Li[3], Dr Yong Wu[3], Siyuan Liu[3], Associate Professor Ling Li[3], Dr Weiqiang Chen[3], Dr Qingxiang Meng[3], Dr Hao Feng[2,4], Hackett Professor Kadambot Siddique[1]

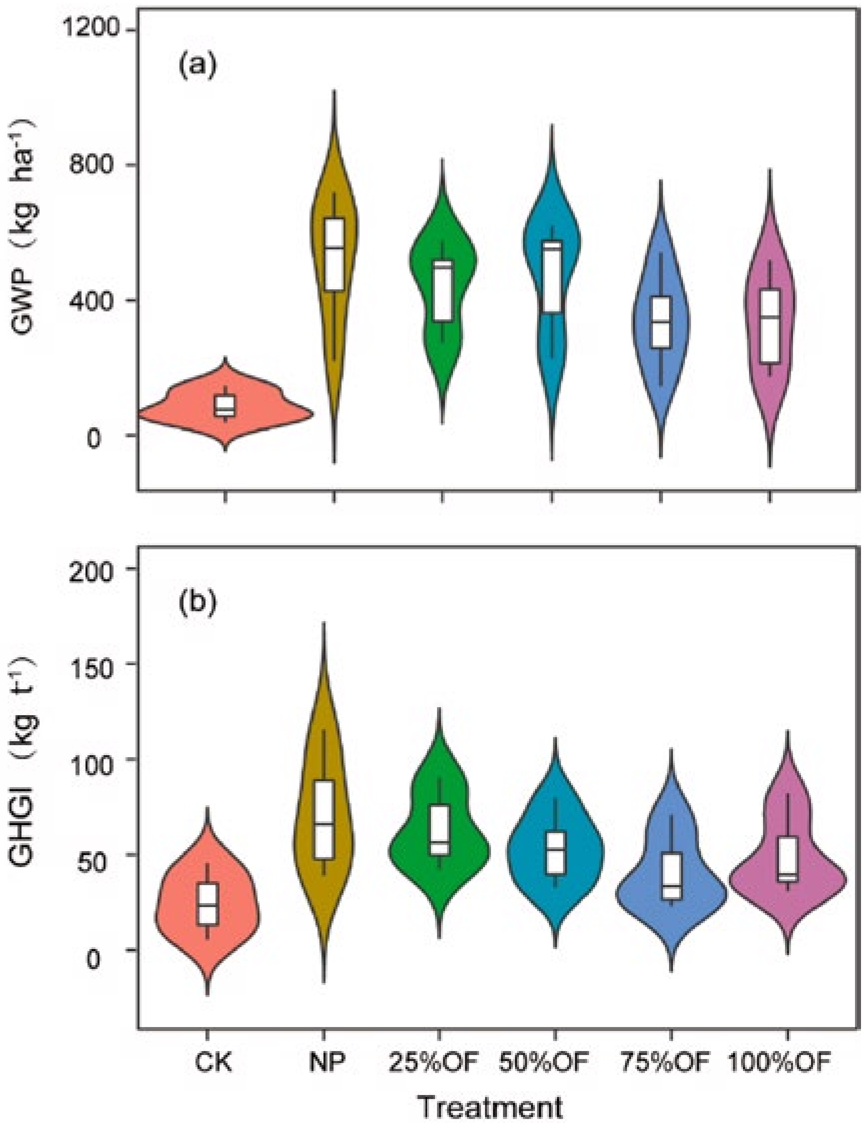
Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]Henan Agricultural University, China; [4]Chinese Academy of Sciences and Ministry of Water Resources, China

Combining organic and inorganic fertiliser applications can help reduce inorganic fertiliser use and increase soil fertility. However, the most suitable proportion of organic fertiliser is unknown, and the effect of combining organic and inorganic fertilisers on greenhouse gas (GHG) emissions is inconclusive. This study aimed to identify the optimum ratio of inorganic fertiliser to organic fertiliser in a winter wheat–summer maize cropping system in northern China to achieve high grain yields and low GHG intensities.

The study compared six fertiliser treatments: no fertilisation (CK), conventional inorganic fertilisation (NP), and constant total nitrogen input with 25 per cent (25 per cent), 50 per cent (50 per cent), 75 per cent (75 per cent), or 100 per cent (100 per cent) organic fertiliser. The results showed that the 75 per cent treatment increased the winter wheat and summer maize yields the most, by 7.2–25.1 per cent and 15.3–16.7 per cent, respectively, compared to NP. The 75 per cent and 100 per cent treatments had the lowest nitrous oxide (N_2O) emissions, 187.3 per cent and 200.2 per cent lower than the NP treatment, while all fertiliser treatments decreased methane (CH_4) absorption (by 33.1–82.0 per cent) compared to CK. Carbon dioxide flux increased in the summer maize growing season (by 7.7–30.5 per cent) compared to CK but did not significantly differ between fertiliser treatments. The average global warming potential (GWP) rankings across two wheat–maize rotations were NP > 50 per cent > 25 per cent > 100 per cent > 75 per cent > CK, and greenhouse gas intensity (GHGI) rankings were NP > 25 per cent > 50 per cent > 100 per cent > 75 per cent > CK.

We recommend using 75 per cent organic fertiliser/25 per cent inorganic fertiliser to reduce GHG emissions and ensure high crop yields in wheat–maize rotation systems in northern China.

This research is supported by the National Key R&D Program of China, National Natural Science Foundation of China, Fundamental Research Funds for the Central Universities, Science and Technology Innovation Funds of Henan Agricultural University, and the 111 Project.



Global warming potential (GWP) and greenhouse gas intensity (GHGI) in different chemical and organic fertiliser treatments in the 2018–2020 winter wheat and summer maize growing seasons.

Integrating crop and soil nutrient management for higher wheat grain yield and protein concentration in dryland areas

Project team: Dr Zhaohui Wang[2] (project leader; w-zhaohui@263.net), Associate Professor Chao Li[2], Dr Jun Yang[2], Zhaomin Li[2], Dr Xingshu Wang[2], Zikang Guo[2], Yi Tian[2], Dr Jinshan Liu[2], Di Zhang[2,3], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]Yangling Vocational & Technical College, China

Wheat grain protein concentration (GPC) is a key parameter related to processing quality and amino acid intake. However, synchronously enhancing grain yield (GY) and GPC is still challenging due to the physiological competition between carbon and nitrogen.

This study determined plant and soil nutrients and surveyed yield and management data from 304 wheat fields at three locations on the Loess Plateau of China to explore limitations and design practices for producing high-yielding and high-protein wheat sustainably. Based on the overall average GY (4732kg ha–1) and GPC (13.1 per cent), the surveyed fields were grouped into low yield & low protein (LyLp), low yield & high protein (LyHp), high yield & low protein (HyLp), and high yield & high protein (HyHp), with average GYs of 3625, 3653, 5912, and 5962kg ha–1 and GPCs of 11.2 per cent, 15.2 per cent, 11.7 per cent, and 14.9 per cent, respectively. The GY has significant positive correlations with cultivar release year (r = 0.192), plant density (r = 0.204), and soil total nitrogen (r = 0.131), a negative correlation with sowing date (r = −0.257), but no correlations with fertiliser rates and soil available nutrients of nitrogen, phosphorus, and potassium. Nitrogen and potassium requirements in HyHp fields were 25.1 per cent and 16.4 per cent higher than that in HyLp fields. Accordingly, HyHp fields had significant higher nitrogen and potassium fertiliser rates and soil nitrogen and potassium supplies than HyLp fields.

A golden wheat field growing in northern China.

Structural equation modelling showed that cultivar release year contributed the most to the GY variations, while soil available potassium has the largest effect on the GPC. In addition, soil nitrogen surplus was approximately 50 per cent decreased from low - to high-yielding fields, but did not differ between HyLp and HyHp fields.

These findings indicate that the integrated crop and soil management strategies, including improved newer cultivar, timely sowing date, advisable plant density and fertiliser rates, and adequate soil nutrients supply, are applicable for the complicated and changeable wheat production environments to improve GY and GPC synchronously.

This research is supported by the National Key Research and Development Program of China, and China Agricultural Research System (CARS-3).

Screening wheat genotypes under UWA controlled environment rooms.

Characterisation and evaluation of major quantitative trait loci for heat stress tolerance in bread wheat (*Triticum aestivum* L.)

Project team: Mukesh Choudhary[1] (project leader; mukesh.choudhary@research.uwa.edu.au), Professor Wallace Cowling[1], Professor Guijun Yan[1], Hackett Professor Kadambot Siddique[1]

Collaborating organisation: [1]UWA

Bread wheat (*Triticum aestivum* L.) is sensitive to high temperature during flowering. Heat waves exceeding 30°C in the afternoon during flowering reduce final yield due to a reduction in the number and size of grains. The impact of heat stress is usually studied during anthesis and seed set, but we evaluated heat stress during meiosis, some 14 to 18 days before anthesis.

In 2023, gene expression studies in wheat genotypes with and without heat stress during meiosis led to the discovery of unique gene expression patterns associated with heat tolerance and heat sensitivity.

PhD candidate Mukesh Choudhary submitted his PhD thesis, based on this project for examination 27 November 2023.

This research is supported by the UWA International Fee Offset and University Postgraduate Award.

The Merredin nitrogen trial, pictured in August 2023.

The effect of in-season split nitrogen applications on wheat grain protein composition

Project team: Professor Harvey Millar[1] (project leader; harvey.millar@uwa.edu.au), Samantha Harvie[1], Dr Hui Cao[1], Dr Katharine Belt[1]

Collaborating organisation: [1]UWA

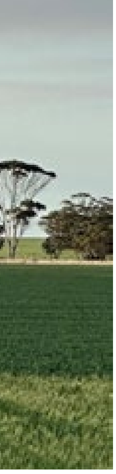
Understanding the impact of nitrogen on wheat protein composition is crucial for enhancing the agronomic and commercial value of wheat. In South Australia, it has been found that in-season split nitrogen applications can increase total grain protein without compromising yield, however, it is unknown if this would also be possible for the arid Western Australian soils. In addition, it is unknown if in-season split nitrogen applications affect protein composition, which may hold significant commercial value.

This research project utilises a proteomic approach to analyse how different nitrogen management strategies effect the protein composition of wheat grown in the arid Western Australian soils. The primary aim of this research is to determine the influence of split nitrogen applications on wheat grain yield, total protein content and protein composition. This will provide a detailed agronomic and molecular understanding of the effects of nitrogen management on wheat grain quality.

In 2023, a comprehensive field trial was conducted at DPIRD in Merredin. The trial involved four nitrogen amount treatments and two split nitrogen applications at week six and 12 and six commercial wheat varieties.

Initial findings indicated that the timing of split nitrogen application did not significantly affect the overall yield or total protein percentage of the wheat. However, split nitrogen applications demonstrated a potential influence on protein abundance. Proteomic analysis revealed significant differential expression of proteins related to various functions such as storage, stress response, major carbohydrate metabolism, protein synthesis, chaperone activity, DNA synthesis, glycolysis, development, and protein degradation. Notably, proteins such as alpha-amylase inhibitor and high molecular weight gluten subunit exhibited differential expression based on the timing of nitrogen application. Importantly, split nitrogen applications did not negatively impact agronomic traits, suggesting the practicality of this approach in farming scenarios, particularly in dry years.

The significance of this work is demonstrated by the finding that nitrogen application in terms of the amount and timing of nitrogen can significantly influence wheat grain protein composition, which could lead to downstream grain quality changes.



Harvest of the Merredin nitrogen trial, with PhD candidate Samantha Harvie (second from right).

By providing a deeper molecular understanding of how nitrogen influences protein composition, the findings can lead to the development of tailored nitrogen application strategies that optimise wheat quality and yield. Such advancements will contribute to sustainable agricultural practices, enhancing the commercial value of wheat, improving seed storage and germination, and bolstering crop resilience. The identification of specific protein biomarkers may also inform future breeding programs and product development, ultimately benefiting growers and the agricultural industry at large. Overall, the insights gained from this study could have a lasting impact on wheat production and agricultural sustainability.

This research is supported by UWA, the Sir Eric Smart Scholarship in Agricultural Research, and GRDC Research Scholarship.

Heat treatment effects pictured as part of the experiment.

Physiological and proteomics approaches for heat stress tolerance in bread wheat (*Triticum aestivum* L.)

Project team: Agyeya Pratap[1], Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au), Associate Professor Nicolas Taylor[1], Professor Madan Pal[2], Dr Viswanathan Chinnusamy[2]

Collaborating organisations: [1]UWA; [2]Indian Agricultural Research Institute, India

PhD candidate Agyeya Pratap presenting at the GRDC Grains Research Update.

Heat stress has detrimental effects on global bread wheat productivity. The aim of our study was to identify proteomic biomarkers for heat tolerance in wheat. We compared physiology, yield, and protein abundance changes of wheat genotypes with contrasting heat tolerance (two tolerant [RAJ3765 and HD2932] and two susceptible [HD2329 and HD2733]) under short-term and long-term heat stress (32°C) at ear peep.

This experiment revealed that heat tolerant genotypes maintained grain yield per plant under both short and long-term heat exposure by maintaining photosynthesis, membrane stability, chlorophyll content, phenology, pollen viability, and redox homeostasis. We identified 31 and 60 differentially abundant proteins in flag leaves and spike tissues, respectively. These proteins can be used as biomarkers for heat tolerance in future breeding programs.

This research is supported by the UWA Scholarship for International Research Fee and Co-funded University Postgraduate Award.

Targeting high nutrient efficiency to reduce fertiliser input in wheat production of China

Project team: Professor Zhaohui Wang[2] (project leader; w-zhaohui@263.net), Dr Saibin Hou[2], Haiyan Dang[2], Tingmiao Huang[2], Qiannan Huang[2], Associate Professor Chao Li[2], Xiaohan Li[2], Professor Yingying Sun[2], Hongxin Chu[2], Weihong Qiu[2], Associate Professor Jinshan Liu[2], Dr Mei Shi[2], Professor Gang He[2], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China

Green wheat growing in the field.

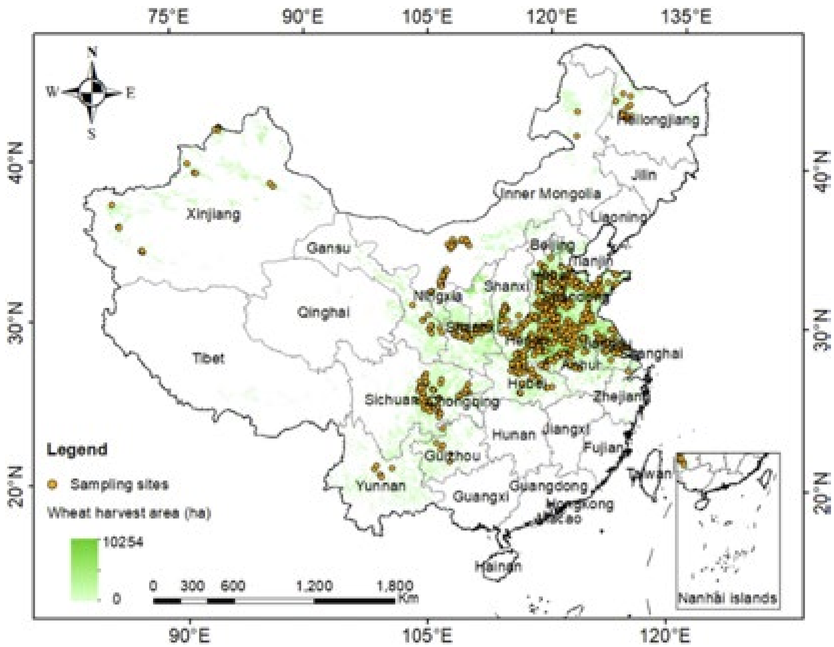
Excessive fertilisation reduces fertiliser efficiency and farm economic benefits and causes various environmental problems. This study aimed to produce high grain yield and protein content for wheat production in China using a high nutrient-use efficiency based fertiliser recommendation method (High NUFER) and limits for crop nutrient physiological efficiency and partial factor productivity of fertiliser.

A farm survey covering 1575 fields was carried out in 17 major wheat production provinces in China from 2015 to 2019. The on-farm information included wheat planting area, varieties, field management, soil nutrient status and fertilisation status, and wheat plant and soil samples were also collected from farmers' fields for measurement and analysis. The High NUFER proposed in this paper was verified in 46 sites in seven major wheat production provinces from 2020 to 2021.

For the average grain yields > 6.0t ha^{-1} and protein content 13.0 per cent in major wheat production regions of China, the nutrient physiological efficiency of wheat should range from 36.5 – 36.8kg kg^{-1} nitrogen (N), 261.3–273.9kg kg^{-1} phosphorus (P), and 53.0–54.3kg kg^{-1} potassium (K), and partial factor productivity of N, P, and K fertilisers should range from 35.9 – 41.9, 153.5–177.9, and 132.5–158.9kg kg^{-1}, respectively, when soil available nutrients ranged from 19.0 to 21.8mg kg^{-1} available N (nitrate-N + ammonia-N), 22.4–26.1mg kg^{-1} available P, and 153.9–157.3mg kg^{-1} available K. Using the High NUFER, China should save 0.62MT yr^{-1} N fertiliser, 0.36MT yr^{-1} P fertiliser, and 0.22MT yr^{-1} K fertiliser, with an additional economic benefit of 1.1 billion USD yr^{-1} and reduction in greenhouse gas (GHG) emissions of 8.91MT CO_2 eq yr^{-1} in major wheat production regions.

The High NUFER can reduce farmers' fertiliser input, thereby increasing economic benefits and decreasing GHG emissions. The High NUFER proposed in this paper has practical value for nutrient management in China and is a potential reference for other wheat-growing countries.

This research is supported by the China Agricultural Research System (CARS-3) and the National Key Research and Development Program of China.



Location of the 1575 wheat fields investigated in China from 2015 to 2019.

Improving wheat yield through increases in heat tolerance of leaf carbon exchange

Project team: Associate Professor Nicolas Taylor[1] (project leader; nicolas.taylor@uwa.edu.au), Professor Harvey Millar[1], Professor Owen Atkin[2], Associate Professor Danielle Way[2], Dr Andrew Bowerman[2], Dr Andrew Scafaro[2], Dr Florence Danila[2], Professor Bob Furbank[2], Professor Barry Pogson[2], Dr Onoriode Coast[3], Dr Rebecca Thistlethwaite[4], Dr William T. Salter[4], Professor Richard Trethowan[4], Dr Joanna Melonek[1,2], Professor Tracy Lawson[5], Professor Elizabete Carmo-Silva[6], Dr Daniel Mullan[7], Dr Aanandini Ganesalingam[7], Dr Alison Bentley[8], Dr Matthew Reynolds[8]

Collaborating organisations: [1]UWA; [2]Australian National University; [3]The University of New England; [4]The University of Sydney; [5]University of Essex, UK; [6]Lancaster University, UK; [7]InterGrain; [8]International Maize and Wheat Improvement Center (CIMMYT)

The sensitivity of wheat yields to heat is intricately linked to the temperature response of key metabolic processes governing photosynthetic CO_2 assimilation during the day and dark respiration at night. Elevated temperatures induce heat stress, reducing photosynthesis and increasing respiration, limiting sugar availability for biomass and grain development. To cultivate heat-tolerant wheat germplasm, understanding and targeting the heat sensitivity of these processes are crucial.

The project aims to identify and target heat-sensitive metabolic steps, including photosynthetic electron transport, Rubisco activation, stomatal closure, and respiratory CO_2 release. To do this a rapid, non-invasive hyperspectral reflectance will be deployed to quantify the heat sensitivity of photosynthesis and respiration. In 2023, the team have collected data to aid in the identification of key heat-sensitive steps using high-throughput robotic and reflectance tools to screen for heat tolerance, revealing heritability and the environmental plasticity in wheat traits.

The project aims to revolutionise wheat breeding by developing novel heat-tolerant germplasm. By screening diverse wheat populations for heat responses, the team will deliver high-throughput, cost-effective tools for accurate selection in breeding programs. The project's impact lies in defining key metabolic traits determining yield in hot climates and facilitating their incorporation into genomic selection approaches for comprehensive trait stacking.

This research is supported by the GRDC, with in-kind contributions provided by partner organisations, including the ANU Centre for Entrepreneurial Agri-Technology, UK-based experts, and CIMMYT.

Ewen McCabe, Agyeya Pratap, Owie McCarthy and James Kelly with the field research setup to measure photosynthesis, respiration and hyperspectral reflectance of line with contrasting heat tolerance.

James Kelly measuring wheat flag leaf photosynthesis using a Licor 6400XT.

Left:
Oats sown at 110mm on the left vs 40mm on the right. Mesocotyl is between the coleoptile and the seed, and oats are the only cereal to have it.

Right:
UWA Master's student Angelia Tanu with InterGrain's national oat breeder Dr Allan Rattey in Kunjin with one of the field experiments.

Genetic diversity and field validation of oats' coleoptile and mesocotyl length for successful establishment in deep-sown conditions

Project team: Angelia Tanu[1] (project leader; tanuangelia@gmail.com), Dr Allan Rattey[2], Professor Erik Veneklaas[1], Dr Sarah Rich[3], Dr Andrew Fletcher[3]

Collaborating organisations: [1]UWA; [2]InterGrain; [3]CSIRO

Angelia Tanu (second to the left) with the CSIRO team Dr Andrew Fletcher, Andrew Toovey, Dr Sarah Rich screening oats' mesocotyl and coleoptile length and amazed with its long combined lengths.

Early sowing and deep sowing have revolutionised Australian winter grain cropping, enhancing germination rates, yields, and mitigating risks associated with unreliable rainfall. However, successful implementation of this practice is dependent on the crop's ability to emerge from depth, where sufficient soil moisture is typically available. Oats (*Avena sativa* L.) are the only winter-cereal with a mesocotyl, an organ between the seed and the coleoptile, enabling emergence from deeper sowing depths (50-200mm). While previous studies have indicated that oats possess long combined mesocotyl and coleoptile lengths, these findings were based on smaller subsets and lacking field validation.

Our research aims to examine the genetic differences in oats' mesocotyl and coleoptile length, temperature effects on these traits, and field validation of deep-sown oats compared to wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). By exploring these factors, breeders will gain valuable insights into the range of variation in current varieties and establish a validated method for screening these traits. The genetic diversity examined encompass international, Australian, and unreleased oat varieties.

Screening 195 oat varieties revealed long combined lengths (112-219 mm), highlighting oats' suitability for deep sowing. However, temperatures above 20°C affected these traits, reducing coleoptile and mesocotyl length by 3.67mm and 1.05mm per °C, respectively. Field experiments conducted in 2023 compared shallow (40mm) and deep (110mm) sowing for oats, wheat, and barley varieties. Notably, for oat varieties the emergence from the 110mm sowing depth was at least 76 per cent of that from the 40mm shallow sowing depth. In contrast, for wheat and barley varieties those numbers were only 50 per cent and 43 per cent respectively, due to their lack of a mesocotyl.

Early sowing practices may expose seedlings to higher soil temperatures, potentially exceeding 30°C in the Western Australian wheatbelt during sowing. Even though hotter temperatures significantly decrease, coleoptile and mesocotyl lengths, we found genetic potential in international germplasm to increase oats' mesocotyl length through breeding, as it has high heritability value (0.85) and no correlation with coleoptile length, mitigating the impacts of climate change.

Oats, with their long combined lengths, are a promising option for early and deep sowing systems. Incorporating oats into these practices offers economic benefits through increased emergence rates and enhanced frost resistance, making them a valuable winter cereal crop for adapting to changing climatic conditions.

This research is supported by UWA and the Processed Oat Partnership program supported by the WA Government.

UWA Research Officers Karen Nelson and Dr Aneeta Pradhan with Professor Wallace Cowling in the rapid-cycle growth room for rapid backcrossing of the new lupin flowering gene into cultivated varieties.

Expanding phenological diversity in narrow-leafed lupin using novel flowering time genes

Project team: Professor Wallace Cowling[1] (project leader; wallace.cowling@uwa.edu.au), Karen Nelson[1], Dr Aneeta Pradhan[1]

Collaborating organisation: [1]UWA

This project began at UWA in September 2023 with the aim of transferring a new flowering time gene from wild lupins to elite cultivated lupin varieties. The project will undertake rapid backcrossing of the new gene to elite lupin cultivars with the aid of molecular markers. This project builds on previous research at UWA funded by GRDC and Council of Grain Grower Organisations (COGGO) Research Fund with industry collaborator Australian Grain Technologies Pty Ltd.

A single gene (*Ku*) has been used in the breeding of narrow-leafed lupins in Western Australia since the 1960s, and it is important to find a wider range of flowering time genes to expand the range of environments for lupin production. The new allele *LanFTc1-P22660* delays flowering by five to 15 days which will be useful for early sowing or longer growing seasons.

Current lupin varieties are not well adapted to early sowing and not suitable for longer growing seasons in higher rainfall zones. This project will enhance the phenological diversity of commercially cultivated lupins available to Australian lupin breeders.

The new *LanFTc1-P22660* allele will provide Australian lupin growers access to mid-season lupin varieties with better adaptation to early sowing and higher rainfall zones, improved harvest height and greater yield potential.

This research was supported by the GRDC and COGGO Research Fund, with industry collaborator AGT Pty Ltd.

Improving canola heat tolerance – A coordinated multidisciplinary approach

Project team: Dr Sheng Chen[1] (project leader; sheng.chen@uwa.edu.au), Dr Yaseen Khalil[4], Damian Jones[5], Professor Wallace Cowling[1], Hackett Professor Kadambot Siddique[1], John Quealy[1], Xiaojie Hu[1], Dr Aldrin Cantila[1], Dr Rajneet Uppal[2], Dr Suman Rakshit[3],

Collaborating organisations: [1]UWA; [2]NSW DPI; [3]AAGI; [4]Kalyx, WA; [5]Irrigation Farmers Network, Victoria

This GRDC-funded national project aims to find heat stress tolerance in genetically diverse canola, discover heat tolerance genes and make them available to canola breeders. UWA co-ordinates this project, which is a collaboration between the University, NSW Department of Primary Industry (NSW DPI) and the Analytics for the Australian Grains Industry (AAGI). The research involves controlled-environment and field-based experiments to discover and validate genes for canola heat stress tolerance.

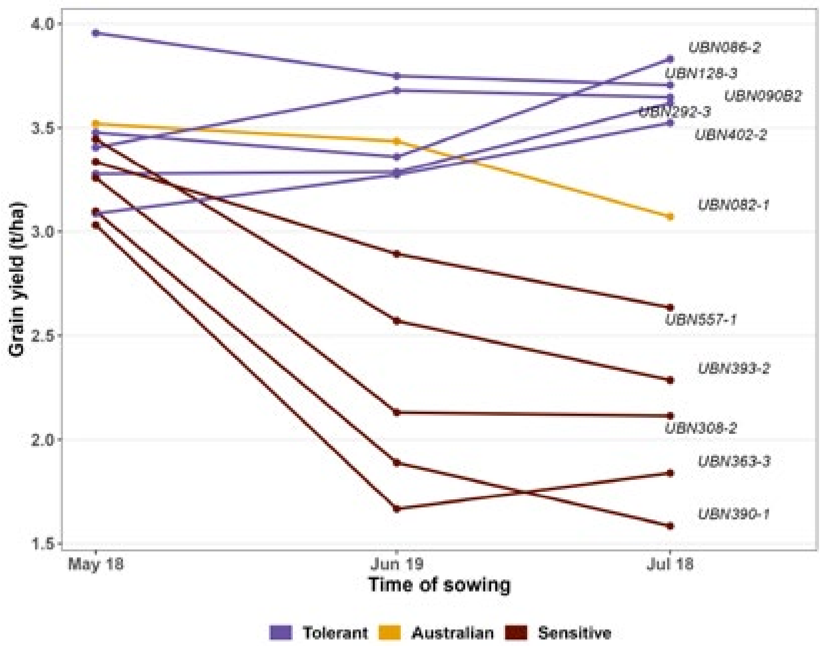
Based on three years of research (2020, 2021 and 2022) in the Heat Screening Facility at the UWA Shenton Park Field Station, some genotypes with different tolerance to heat stress or capacity to recover after heat stress were selected for field trials in 2023, together with several Australian canola cultivars.

In 2023, 48 genotypes were successfully validated at 5 different sites in Australia, i.e., Dongara WA, Kerang VIC, Leeton NSW, Narrabri NSW and Condobolin NSW. 2023 is the hottest year in Australian record. The canola lines in late sowings at all 5 sites were challenged with heat waves during flowering and grain filling stages. As an example, Figure 1 shows the grain yield performance of 11 representative lines selected from 48 canola lines tested in Leeton, NSW in 2023. AV Ruby, a line in yellow colour, is an Australian canola cultivar that is relatively heat sensitive – 12.8 per cent yield loss in late sowing comparing to early sowing, representing the heat tolerance status of current Australian canola cultivars. The heat tolerant lines showed high grain yield at all 3 times of sowings. These lines will be delivered to Australian canola breeders in 2024. The heat sensitive lines showed dramatic grain yield loss (33.2 per cent on average) in late sowings comparing to early sowing. These results are consistent with what we found in the Heat Screening Facility at UWA's Field Station.

A field trial was successfully completed using potable heat chambers at NSW DPI (Wagga Wagga). 16 genotypes were assessed in a replicated experiment in 6m long, three-row plots for heat tolerance at early flowering. This trial was selected as a show case to demonstrate to national and international canola researchers as part of the 16th International Rapeseed Congress.

UWA researchers also conducted genome-wide association study (GWAS) on a total of 324 canola lines. 154 significant marker-trait associations (MTAs) were specifically associated with heat tolerance indices, percentage change (PC), or stress tolerance index (STI), involving 32 SNP markers. Notably, nine SNP markers exhibited a high pleiotropic effect by being associated with at least 5 phenotypes in the study. 128 genes possibly related to

The grain yield performance of 11 representative lines selected from 48 canola lines tested in Leeton, NSW in 2023.
Credit: Dr Suman Rakshit from AAGI



heat stress tolerance were found in 32 QTLs. They belong to 36 gene groups, including ATP-binding cassette, Auxin-related protein, large subunit ribosomal protein, MATE family, MFS transporter, protein kinases, transcription factors, etc. Six heat-responsive genes were identified, including two HSFs, two HSP90s, an HSP40, and an HSP70-interacting protein. We also investigated multi-locus genotype patterns derived from 9 pleiotropic SNP markers, used them to identify heat-tolerant and heat-sensitive materials among 48 genotypes, which were consistently tested over three years in the Heat Screening Facility at UWA's Shenton Park Field Station.

So far, we have confirmed the value of heat stress tolerant canola genotypes in multi-environment field trials and identified genes/QTLs associated with heat stress tolerance. The heat tolerant germplasm, functional markers/genes, together with relevant methodologies, will be provided to canola breeders for breeding of heat stress tolerant canola cultivars in 2024.

This research is supported by the GRDC, UWA and NSW DPI.

Flowering canola in a field in York, Western Australia.

UWA canola breeding technicians Jasenka Vuksic and Rozlyn Ezzy in the field scoring canola plots for blackleg disease resistance.

Pre-breeding of canola and field peas

Project team: Professor Wallace Cowling[1] (project leader; wallace.cowling@uwa.edu.au), Jasenka Vuksic[1], Rozlyn Ezzy[1], Felipe Castro-Urrea[1]

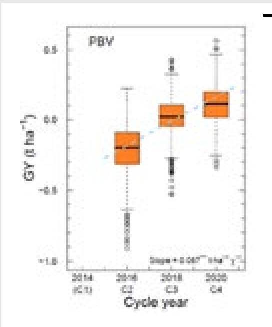
Collaborating organisations: [1]UWA; NPZ Lembke, Germany

NPZ Lembke in Germany has funded projects at UWA since 2000 for pre-breeding of canola (spring oilseed rape) and field peas. These projects clearly demonstrate the industry impact of UWA research based on national and international collaboration, with 37 new canola varieties released since 2003. These varieties have added significant value to Australian canola growers.

A major research output from this project in 2023 was the demonstration of world-leading genetic gain in canola yield, disease resistance and other economic traits by Professor Cowling and team (*Plants* 2023 12:383). The population also retained high genetic diversity from optimal contributions selection which increased the potential for long-term genetic gain.

PhD student Felipe Castro-Urrea demonstrated the value of multivariate analysis to improve low-heritability traits in field peas, and in 2023 he validated his glasshouse results in a pea field trial at Boddington, Western Australia (image below). Mr Castro-Urrea is using whole-genome markers in the pea breeding population to evaluate the accuracy of genomic information to predict future performance for these low-heritability traits.

This research is funded by UWA and NPZ Lembke, Germany.



World leading genetic gain in canola breeding (from Plants 2023 12:383). Predicted breeding values for grain yield (GY) are increasing by 4.1 per cent per year.

Field pea field trial in 2023 at Boddington, Western Australia.

Diadegma semiclausum parasitoid wasp (left) and diamondback moth larvae (right).

PhD candidate Amber Balfour-Cunningham checking a Diamondback moth pheromone trap in flowering canola.

Natural enemies of diamondback moth, *Plutella xylostella,* in WA canola crops: Impacts and monitoring techniques

Project team: Amber Balfour-Cunningham[1,2,3] (project leader; amber.balfour-cunningham@research.uwa.edu.au), Professor Ken Flower[1], Dr Sarina Macfadyen[3], Dr Dustin Severtson[1,2], Associate Professor Michael Renton[1]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]CSIRO

This project focuses on improving monitoring and knowledge of natural enemies of diamondback moth *Plutella xylostella* (DBM) in canola, to increase confidence in pest management decisions. This will also support access to premium canola seed markets and aid preservation of available chemistries through management of pest insecticide resistance.

In 2023, 20 grower-managed canola focus paddocks across the WA grainbelt were monitored fortnightly for DBM moths, larvae and winged natural enemy predators and parasitoids. Parasitoid wasps, like the creature in the *Alien* movie, lay their eggs inside or on living hosts. The larvae then hatch and consume their host from the inside out, killing them.

A key finding was that larval parasitoid wasps impacted DBM larvae only in Southern region canola crops. In 2023, 75 per cent of canola focus paddocks in the Great Southern were found to have DBM parasitised by one species of parasitoid wasp, *Diadegma semiclausum.* no hyperparasitoids, which parasitise parasitoids, were found. More than 60 per cent of DBM larvae were parasitised in some populations collected in 2023 from the Mount Barker and South Stirlings canola sites. As parasitised and unparasitised are visually identical, it makes monitoring of parasitism difficult, along with decision making for application of insecticides.

Additionally, a controlled glasshouse study was conducted in 2023, which found that larval parasitoid wasps increase DBM mortality both directly through parasitism, through interrupting the pest's life cycle, and indirectly through changes to the pest larvae's behaviour, such as increasing escape behaviours and reducing feeding on canola.

The research is ongoing, and another aim is to determine factors that contribute to the presence of DBM natural enemies in broadacre grain growing regions, and the most suitable monitoring methods for canola growers and advisors. Improving understanding and utilisation of 'free' biological control by natural enemies present in the landscape is especially crucial for control of Diamondback moth. This is due to this pest's rapid life cycle, extreme ability to develop insecticide resistance and the high costs of chemical control.

This research is supported by UWA and the GRDC.

Heat stress during gametophyte development reduces subsequent floret fecundity in oilseed rape (*Brassica napus* L.)

Project team: Xiaojie Hu[1], Professor Wallace Cowling[1] (project leader; wallace.cowling@uwa.edu.au), Dr Sheng Chen[1], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; UWA Centre for Microscopy, Characterisation and Analysis

Oilseed rape (*Brassica napus* L.), also known as canola, is sensitive to high temperatures during flowering, but the impact of heat stress during gametophyte development remains unclear. Gametophyte development and meiosis occurs before flowers open, so we applied heat stress between growth stage BBCH 51 to 57 (see figure showing BBCH growth stages below).

In this study, we selected two cultivars, AV-Ruby and YM11, known for their differing responses to heat stress. We applied precise heat stress (32°C day / 22°C night) and control (25°C day / 15°C night) treatments to evaluate the impact on gametophyte development and subsequent floret fecundity, measured by pod set, seed number per pod, and average seed size.

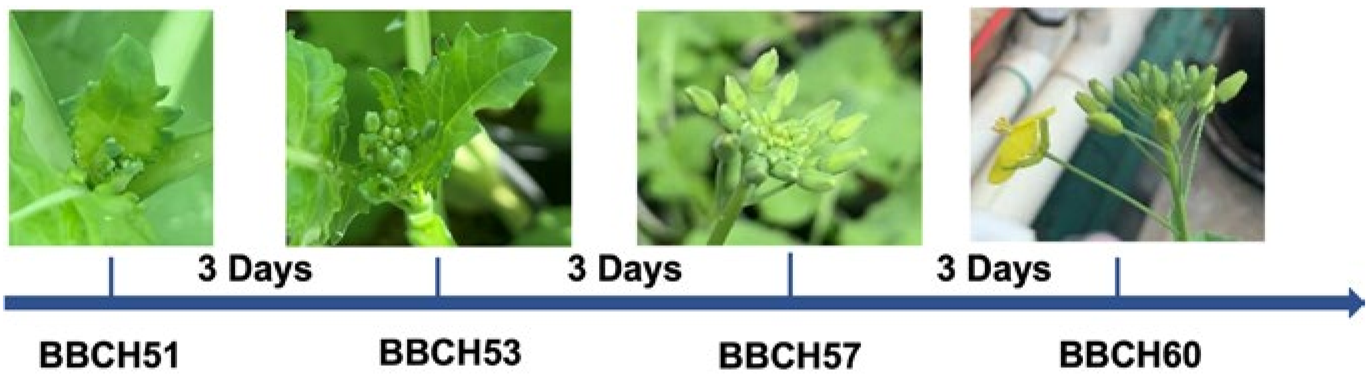
Heat stress during male gametophyte development reduced pollen viability and germination, resulting in fewer pods and seeds per pod. Despite this, pollen tubes successfully reached a high percentage of ovules in both treatments. Heat stress applied to female gametophytes in the first five buds reduced floret fecundity in the lower main stem but increased it in the upper main stem compared to the control.

Overall, heat stress during sporogenesis and gametogenesis in both male and female organs of the two cultivars had a lasting negative impact on the number of pods and seeds per pod but did not affect average seed size. This study enhances our understanding of heat responses in oilseed rape's reproductive organs.

This research is supported by the UWA International Fee Scholarship, China Scholarship Council, and the GRDC.

Control **Heat**

Pod with fewer seeds formed after heat stress. Scale bar = 1 cm.



Development of the main stem inflorescence in the oilseed rape cultivar AV-Ruby using the BBCH scale.

Cotyledons infected with blackleg (*Leptosphaeria maculans*).

Identification of novel QR markers in the canola-blackleg pathosystem using multi-omics

Project team: Jaco Zandberg[1], Professor Jacqueline Batley[1] (project leader; jacqueline.batley@uwa. edu.au), Associate Professor Nicolas Taylor[1], Dr Angela van de Wouw[2], Dr Phillip Bayer[3]

Collaborating organisations: [1]UWA; [2]University of Melbourne; [3]Mindaroo Foundation

Blackleg (*Leptosphaeria maculans*) is a constant global and national threat to *Brassica napus* (canola) yield. The fungal pathogen causes an average 10-15 per cent of yield loss every year, despite rigorous agronomic practice and management strategies. The most effective strategy in curtailing the impact of blackleg diversifying immune resistance. *B. napus* has two branches of resistance against the blackleg pathogen:

1) The major resistance response system defined by the presence of one or multiple qualitative resistance gene(s) (R) that directly recognise specific pathogen markers (*Avr* genes), and
2) The systemic resistance response system defined by the presence of multiple, varied quantitative resistance (QR) genes.

In response to increasing diversity in *L. maculans* populations, farming practices have adapted to reduce the selective pressure applied to in-field pathogen populations by rotating major *R* gene cultivars and rotating crops (e.g. one year wheat, one year canola) to prevent breakdown.

The time taken for *R* gene breakdown can be reduced by the presence of an effective and synergistic QR resistance response system and help to prevent the collapse of a *B. napus* population afflicted by *L. maculans.* Several case studies have shown that QR can be responsible for restricting the spread of infected blackleg when the *R* gene is overcome or evaded, preventing the collapse of the plant. Unfortunately, defining the scope of the QR response system is challenging. This PhD project aims to investigate the role of QR and identify new markers of QR in canola using multi-omic approaches such as integrated proteomics, transcriptomics and metabolomics.

This research is supported by UWA.

PhD candidate Jaco Zandberg in the field for a blackleg nursery trial.

Unveiling disease resistance genes in *Brassica* Species: Identification, characterisation, and evolutionary insights

Project team: Professor Jacqueline Batley[1] (project leader; jacqueline.batley@uwa.edu.au), Dr Aria Dolatabadian[1], Dr Junrey Amas[1], Dr Hawlader Abdullah Al-Mamun[1], Professor David Edwards[1]

Collaborating organisation: [1]UWA

Plant diseases pose a significant threat to global agriculture, impacting crop yield and food security. Understanding the genetic basis of disease resistance is crucial for developing resilient crops. Resistance gene analogs (RGAs) play a pivotal role in plant defence mechanisms. Identifying and classifying these RGAs within the genomes of Brassicaceae species can provide key insights into the molecular mechanisms governing disease resistance.

This study aims to comprehensively investigate the landscape of RGAs in *Brassica nigra, Sinapis arvensis,* and *S. alba* genomes. The specific objectives are:

- Utilise the RGAugury pipeline for the identification and classification of RGAs,
- Examine the distribution and density of RGAs across chromosomes, with a focus on understanding the spatial organisation of different RGA types,
- Identify homologous genes among both RGAs and non-RGAs in each species to gain insights into the broader genetic context of disease resistance,
- Analyse the co-localisation of receptor-like kinases (RLKs) and receptor-like proteins (RLPs) within reported disease resistance loci in Brassica crops, assessing the significance of these associations, and
- Perform phylogenetic analysis of cloned RGAs and QTL-mapped RLKs and RLPs to uncover distinct clusters and enhance our understanding of the evolutionary relationships between these genes.

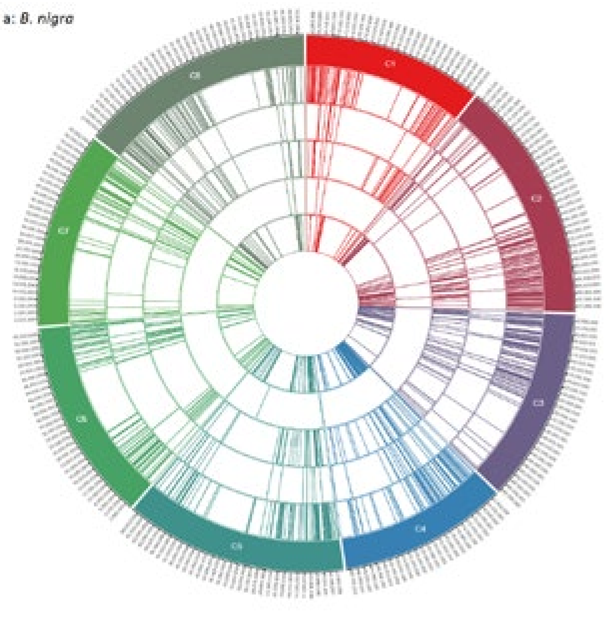
This study employs the RGAugury pipeline to identify and classify RGAs in the genomes of B. *nigra,* S. *arvensis,* and S. *alba.* Among the 4,499 candidate RGAs identified, RLKs were the most prevalent class, followed by transmembrane-coiled-coil proteins (TM-CCs) and RLPs. RGAs tended to cluster at chromosome ends, with distribution variations among types. Pairwise similarity analyses exposed distinct RGA clusters, indicating gene relationships. Homologous genes were identified among RGAs and non-RGAs, shedding light on disease resistance genetics. Co-localisation of RLKs and RLPs within reported disease resistance loci revealed significant associations, while phylogenetic analysis elucidated distinct clusters and evolutionary relationships. These findings advance our understanding of RGAs in Brassicaceae genomes, offering valuable insights for future plant disease resistance and crop improvement research.

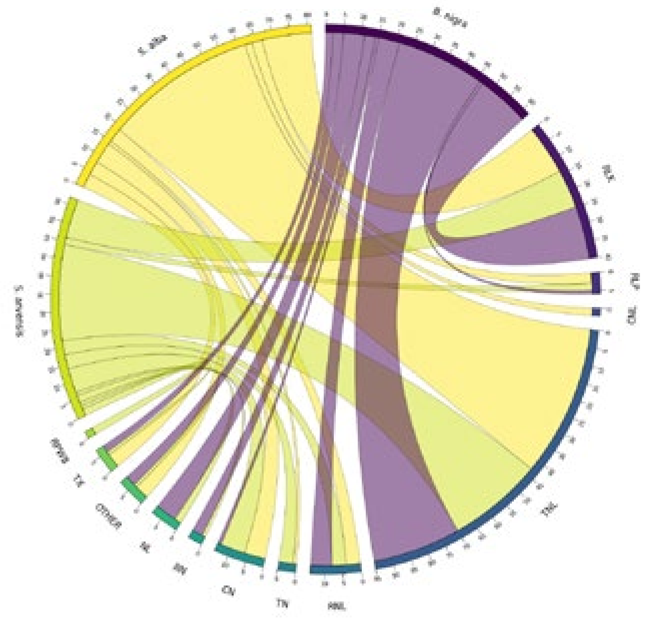
The outcomes contribute crucial knowledge to the ongoing efforts aimed at developing more resilient and productive agricultural systems to address global food security challenges.

This research is supported by UWA and the ARC.

Bottom left:
RGAs positions on the B. nigra chromosomes. Outer to inner, RLK, RLP, TM-CC, RPW8 and NLR.

Bottom right:
The number and distribution of cloned disease resistance gene homologs containing resistance domains including RLK, RLP, CNL, TNL, RNL, TN, CN, RN, NL, TX, OTHER and RPW8 in B. nigra, S. arvensis and S. alba genomes.





Developing molecular markers for blackleg disease resistance breeding and management

Project team: Professor Jacqueline Batley[1] (project leader; jacqueline.batley@uwa.edu.au), Shu Moh Saad[1], Dr Aldrin Cantila[1], Dr Junrey Amas[1], William Thomas[1], Professor Dave Edwards[1]

Collaborating organisations: [1]UWA; The University of Melbourne

Phenotyping set-up for blackleg resistance screening.

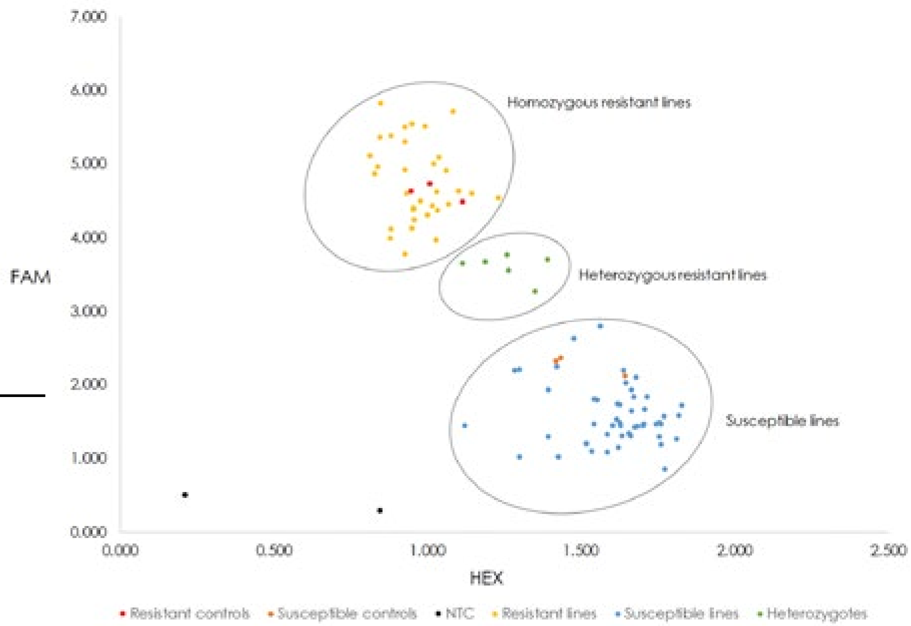
Blackleg disease, caused by the fungal pathogen *Leptosphaeria maculans*, is the most devastating disease affecting canola in Australia. Genetic resistance is the most effective strategy for minimizing the impact of this disease. However, resistance can still be overcome in the field, highlighting the importance of understanding the specific resistance genes present in Australian canola cultivars. In this project, the Crop Genomics Group at UWA is working with Dr Angela van de Wouw from the University of Melbourne to identify and develop molecular markers for three key blackleg resistance genes, *LepR1*, *LepR2*, and *Rlm6*.

To achieve this, a series of phenotypic screenings were conducted on a wide variety of canola lines, including commercial cultivars, using differential blackleg isolates to identify resistant and susceptible lines. The resulting phenotype data was then integrated with single nucleotide polymorphism (SNP) markers from the *Brassica* 90K SNP array and whole-genome resequencing (WGRS) to identify genomic regions associated with *LepR1*, *LepR2*, and *Rlm6*. Subsequently, resistance (*R*) genes within these regions were identified and sequenced in both resistant and susceptible lines. This approach efficiently identified a few candidate genes (3 for *LepR1*, 2 for *LepR2* and 1 for *Rlm6*), which exhibited consistent DNA sequence segregation patterns between resistant and susceptible lines.

For each of these genes, Kompetitive Allele-Specific PCR (KASP) markers were then designed to target specific SNPs that can differentiate resistant and susceptible alleles. The results obtained from genetic screening on over 700 canola lines suggest these markers can accurately predict the phenotypes of these lines. This also indicate that the identified genes are promising candidates for further validation. Moreover, these newly developed markers enable high-throughput screening, which significantly reduces the reliance on time-consuming phenotyping methods. Functional studies are underway to validate these genes using genetic transformation and gene-editing techniques to gain insight into their molecular mechanisms.

These KASP markers will expand the suite of molecular markers previously developed for other blackleg resistance genes, such as *LepR3/Rlm2* and *Rlm4/Rlm7/Rlm9*. The utilisation of these markers has the potential to expedite the breeding process for blackleg-resistant canola lines and enhance the management of this devastating disease.

This research is supported by UWA, the GRDC and ARC.



Results of the Kompetitive Allele Specific PCR (KASP) genotyping on canola cultivars. The marker was able to distinguish resistant lines (homozygous and heterozygous) from the susceptible lines.

A pangenome-based approach for defining the disease resistance gene landscape of *Brassica rapa*

Project team: Professor Jacqueline Batley[1] (project leader; jacqueline.batley@uwa.edu.au), Dr Junrey Amas[1], Dr Aria Dolatabadian[1], Dr Philipp Bayer[2], William Thomas[1], Professor David Edwards[1], Dr Soodeh Tirnaz[1]

Collaborating organisations: [1]UWA; [2]Minderoo Foundation

Brassica rapa (AA, 2n=20) is an agriculturally significant member of the Brassicaceae family, extensively cultivated as both a vegetable and an oilseed crop. It was the first *Brassica* species to be sequenced and is regarded as a model species for understanding the genomic and genetic underpinnings of important agronomic traits within the *Brassica* family.

Similar to most crop species, a wide array of diseases significantly impact the production of *B. rapa*, including blackleg, clubroot, downy mildew, and Turnip mosaic virus (TuMV). The sustainable management of these diseases primarily relies on the utilisation of genetic resistance, driven by disease resistance genes (*R* genes), which can generally be classified into two major types: transmembrane leucine-rich repeats (TM-LRRs) and nucleotide-binding site leucine-rich repeats (NLRs).

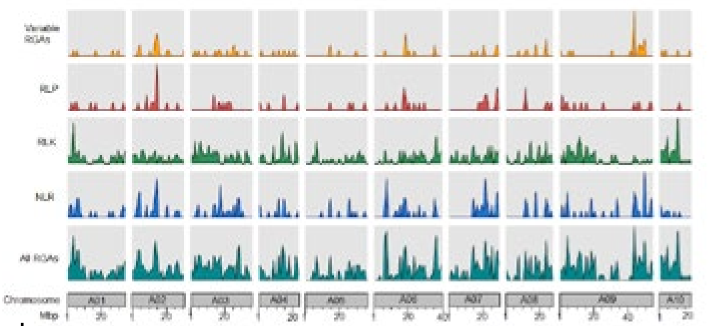
Previous studies have identified *R* genes in *B. rapa*; however, these investigations were primarily based on a single genome reference and do not represent the complete range of *R* gene diversity in *B. rapa*.

This study employed the pangenome of *B. rapa*, which encompassed 71 lines across 12 morphotypes, to comprehensively describe the repertoire of *R* genes in this species. The findings revealed that 309 *R* genes were impacted by presence-absence variation (PAV), a form of genome structural variation (SV). Additionally, 223 *R* genes were identified as missing from the reference genome. These results indicate that a significant portion of the *B. rapa* genome remains uncharacterised, potentially harboring key genes that can be utilised for breeding purposes. This underscores the significance of pangenomes in genomic-based studies of crop species like *Brassica*.

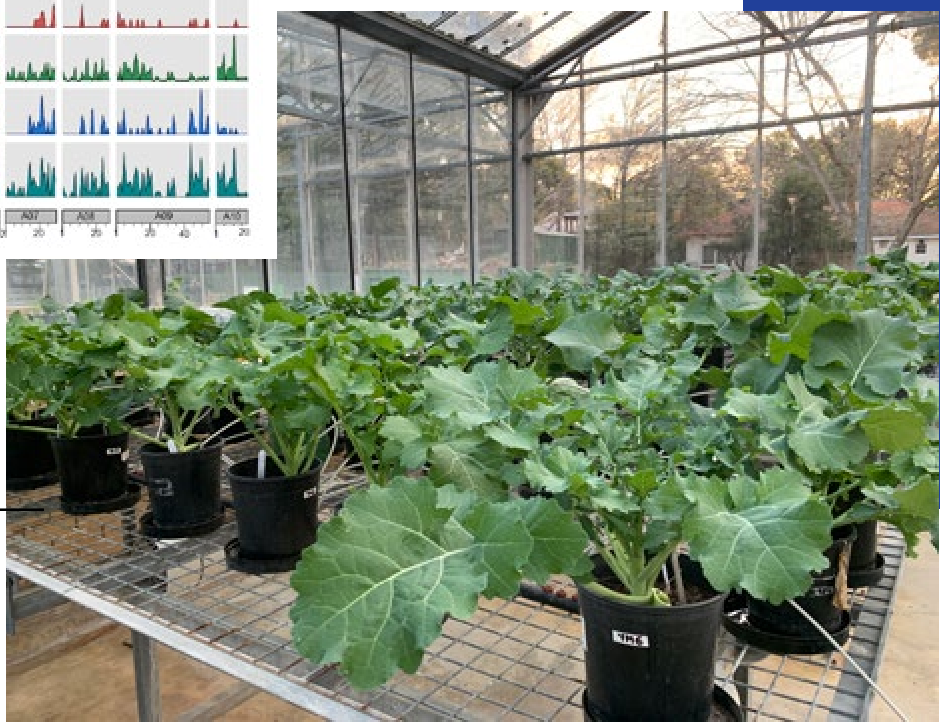
The TM-LRR class exhibited a higher number of core gene types than variable genes, while the opposite trend was observed for NLRs. This suggests that NLRs are more prone to diversification than TM-LRRs. Furthermore, comparative analysis with the *B. napus* pangenome revealed a substantial conservation (93 per cent) of *R* genes between the two species, supporting previous observations demonstrating the close relationship of these related species. Among the identified *R* genes, 138 were located within known *B. rapa* disease resistance QTL, with the majority being subject to negative selection. This indicates the significance of these genes in maintaining resistance against pathogens in this species. Moreover, these genes represent potential candidates that can be explored for breeding.

Published in *Plant Biotechnology Journal* (doi: 10.1111/pbi.14116), this study offers a valuable genomic resource for identifying candidate genes that can be utilised in breeding disease resistance in *B. rapa* and its related species.

This research is supported by UWA and the ARC.



Density of R gene classes in the reference genome.



Brassica species in grown in glasshouse conditions.

Novel resistances provide new avenues to manage Alternaria Leaf Spot (*Alternaria brassicae*) in canola (*Brassica napus*), mustard (B. *juncea*) and other *Brassicaceae* crops

Project team: Professor Martin Barbetti[1] (project leader; martin.barbetti@uwa.edu.au), Dr Hebba Al-Lami[1,2], Dr Ming Pei You[1], Dr Surinder Banga[2]

Collaborating organisations: [1]UWA; [2]Punjab Agricultural University, India

Alternaria leaf spot (*Alternaria brassicae*) can be a devastating disease in canola (*Brassica napus*) and mustard (*B. juncea*) but there are no highly effective host resistances available. Screening of 150 diverse *Brassicaceae* varieties under glasshouse conditions highlighted important novel resistances, in particular, *Camelina sativa* 4076 and *Diplotaxis erucoides* Wasabi Rocket with complete resistance across disease assessment parameters (leaf incidence [per cent LDI], severity [per cent LAD], consequent defoliation [per cent LCI]).

Next most resistant were *C. sativa* CSA (per cent LDI 0.6; per cent LAD 0.4), 4144 (per cent LDI 1.2; per cent LAD 0.5), 405 (per cent LDI 1.7; per cent LAD 0.7), *C. sativa* 3274 (per cent LDI 2.5; per cent LAD 0.8), *Carrichtera annua* CAN3 (per cent LDI 7.7; per cent LAD 4.0) and *Sisymbrium irio* London Rocket (per cent LDI 2.1; per cent LAD 0.8), all with per cent LCI values of 0. Other genotypes showing high level resistance included *S. erysimoides* SER 4 (per cent LDI 11.8; per cent LAD 5.6; per cent LCI 0), *D. cardaminoides* wild rocket (per cent LDI 15.5; per cent LAD 7.2; per cent LCI 0), and showing moderate resistance were *Brassica carinata* ML-EM-1 (Rungwe), *B. insularis* Moris, *B. napus* ZY006, *B. oxyrrhina* BOX1, *B. oleracea* var. *capitata* Sugarloaf, *B. tournefortii* CN01-104-2 and *Sinapis alba* Concerta with per cent LDI 21.6-29.8, per cent LAD 12.8-21.0 and per cent LCI 0-5.7.

In particular, B. *napus* ZY006 for canola and *B. oleracea* var. *capitata* cv. Sugarloaf can now be directly utilised, i.e., without crossing impairment, for *Brassica* species and vegetable breeding programs, respectively. While all *B. juncea* genotypes were susceptible, there were some less susceptible varieties from India in comparison with genotypes from Australia or China. The most susceptible test genotype was *Rapistrum sativus* (per cent LDI 89.4; per cent LAD 83.9; per cent LCI 71.0), highlighting the value of the resistances identified.

These findings not only highlight a range of novel resistances against *A. brassicae* for canola/mustard and other diverse *Brassicaceae* breeding programs to develop resistant commercial varieties, but also emphasise highly susceptible varieties to avoid in both breeding programs and commercial situations conducive to Alternaria leaf spot.

This research is supported by UWA.

Typical Alternaria blight symptoms on canola in the field.

New opportunities to improve white mould (*Sclerotinia*) resistance in common bean (*Phaseolus vulgaris*)

Project team: Professor Martin Barbetti[1] (project leader; martin.barbetti@uwa.edu.au), Dr Muhammad Azam Khan[1,2], Dawid Wentzel[1], Dr Ming Pei You[1], Dr Sally Norton[3]

Collaborating organisations: [1]UWA; [2]University of Agriculture, Pakistan; [3]Australian Grains Genebank, Victoria

Typical white mould (Sclerotinia) symptoms on common bean cotyledon, leaf, and stem.

White mould *Sclerotinia sclerotiorum* inflicts major yield losses on common bean (*Phaseolus vulgaris*), yet commercial cultivars known for their high yields and market-adapted grains lack physiological resistance to this disease. To test diverse common bean genotypes for resistance in stem, leaf, and cotyledon tissues, 34 common bean genotypes with a wide range of agronomic traits and grain types, including genotypes noted previously for susceptible and resistant responses to white mould, were inoculated with the prevailing *Sclerotinia* pathotype and assessed for resistance in stem, leaf, and cotyledon tissues.

There was significant variation in resistance responses in stem, leaf and cotyledon tissues across the genotypes. Contender, ICA Bunsi, XAN 280, and Taisho-Kintoki showed the highest resistance in stems, whereas Norvell 2558, Pico de Oro, Sanilac, Othelo and Negro Argel exhibited notable resistance in leaves. Metis, Canario 107, Pico de Oro, Pogonion, and Jubilejnaja 287 displayed the most resistance in cotyledons.

This is the first reported attempt to determine the response of common bean germplasm to a prevalent Australian *Sclerotinia* pathotype. Bean genotypes exhibiting high level resistance to white mould identified in this study can be used as parental lines for crosses in common bean breeding programs and/or directly as improved cultivars.

The study highlights both the value of screening under controlled environment conditions to reliably locate new stem, leaf and/or cotyledon resistances and the possibility of using rapid cotyledon screening to indicate stem resistances because the expression of resistances in cotyledons generally correlated strongly with those in stems.

This research is supported by UWA.

Novel resistances in *Lupinus* spp. against *Sclerotinia* offer opportunities for cost-effective control of Sclerotinia stem rot

Project team: Professor Martin Barbetti[1] (project leader; martin.barbetti@uwa.edu.au), Dr Muhammad Azam Khan[1,2], Dr Ming Pei You[1], Dr Sally Norton[3]

Collaborating organisations: [1]UWA; [2]University of Agriculture, Pakistan; [3]Australian Grains Genebank, Victoria

Stem rot caused by *Sclerotinia sclerotiorum* is a serious, and sometimes devastating, disease of lupins. Two hundred and thirty-six lupin accessions from across 12 *Lupinus* species were screened against the prevailing *Sclerotinia* pathotype. *L. angustifolius* accession 21655 and *L. albus* var. *albus* accession 20589 showed immune and 'near-immune' responses, respectively. Thirteen accessions of *L. angustifolius,* three accessions each of *L. albus* and *L. albus* var. *albus,* and a single accession each of *L. albus* var. *graecus, L. mutabilis, L. palaestinus* and *L. pilosus* (totalling approximately 4 per cent) showed a highly resistant (HR) response. A further 19 accessions of *L. angustifolius,* two accessions each of *L. albus* and *L. pilosus,* and a single accession of *L. mutabilis* (totalling approximately 10 per cent) showed a resistant (R) response. The reactions of 16 (15 *L. angustifolius,* one *L. digitatus*) of these 236 accessions were also compared with their reactions to a different Sclerotinia pathotype. There, five *L. angustifolius* accessions showed a HR response and four showed a R response, and the *L. digitatus* accession showed a moderate resistance (MR) response.

In addition, 328 plants in a 'wild' naturalised field population of *L. cosentini* were screened *in situ* in the field against the prevailing *Sclerotinia* pathotype. Five (approximately 1.5 per cent) of the 328 plants of wild lupin showed an immune response, 63 (approximately 19 per cent) showed a HR response, and 146 (approximately 45 per cent) showed a R response.

We believe this is the first examination of diverse *Lupinus* spp. germplasm responses to a prevalent pathotype of *S. sclerotiorum.* Lupin genotypes exhibiting high level resistance to Sclerotinia stem rot identified in this study can now be used as parental lines for crosses in lupin breeding programs and/or directly as improved cultivars to reduce the adverse impact of this disease on lupin crops.

This research is supported by UWA.

Typical *Sclerotinia* disease symptoms and damage on lupins.

Predicting the impact of possible herbicide loss scenarios can help prepare the industry for changes.

Preparedness for loss of access to significant herbicide use patterns or chemistry: Implications and planning

Project team: Professor Ken Flower[1,2] (project leader; ken.flower@uwa.edu.au), Dr Mike Ashworth[1,2], Dr Michael Widderick[3], Dr Rick Llewellyn[4], Jackie Ouzman[4], Dr David Brunton, Dr Gayle Somerville[1,2]

Collaborating organisations: [1]UWA; [2]Australian Herbicide Resistance Initiative (AHRI); [3]Queensland Government Department of Agriculture and Fisheries; [4]CSIRO

How prepared is the agricultural industry for the possible loss of herbicides? Increasing pesticide resistance, changing national and international grain market demands, and social license pressures are expected to lead to loss of some herbicides or their use patterns, which will significantly change weed management practices. In collaboration with GRDC, it has been identified that herbicide loss will impact the industry more than a simple switch to alternative chemicals, which in themselves can be expensive and result on lower profit.

Predicting the impact of possible herbicide loss scenarios can help prepare the industry for these changes. Four possible scenarios were modelled for a 10-year period, which included loss of all:

a) Use of glyphosate,
b) Knockdown herbicides,
c) Post-emergent and crop-topping herbicides, and
d) Pre-emergent herbicides.

Each scenario was evaluated independently of one another. The overall aim of this project was to assess the potential impact and implications of the four herbicide loss scenarios on weed populations, herbicide resistance, economics at the paddock and national scale, and management options.

At the paddock scale, the loss of glyphosate had the least impact on gross crop margins and weed numbers of all scenarios tested. However, it resulted in greater reliance on paraquat, a scenario currently happening, and therefore increased resistance to paraquat would occur. While increased paraquat resistance is a threat, the modelling showed the loss of glyphosate resulted in more frequent outbreaks of resistance to some pre-emergent (group 15) herbicides, which is a key group of residual herbicides. This was likely due to the rare frequency of the resistance gene for paraquat. Similar cascading effects were seen when modelling the loss of all post-emergent herbicides, with greater reliance on pre-emergent herbicides, and increased risk of weeds developing resistance. Generally, weed control options would decrease, and this would increase the selection pressure on common weed species to develop resistance. Gross margins would be reduced, especially in the cases of loss of all knockdowns, and loss of residual herbicides.

Nationally, all scenarios of herbicide loss would result in increased cost of managing weeds per ha, particularly loss of knockdowns, followed by loss of pre-emergent herbicides. Expenditure would increase through greater use of integrated weed management practices and cost of alternate herbicides.

While herbicides are likely to remain a key weed control component in our cropping systems, the implementation of effective non-herbicidal weed control strategies will become more important to maintain profitability and sustainability in the long-term. This will probably require greater use of IWM tools combined with precision weed management technology.

This research is supported by UWA and the GRDC.

Master's student Luk Lam collecting images during a field experiment at Kokeby in Western Australia.

Image recognition for early detection of brome grass, barley grass and wild oats in wheat

Project team: Luk Lam[1,2], Professor Ken Flower[1,2] (project leader; ken.flower@uwa.edu.au), Dr Michael Ashworth[1,2], Roberto Lujan Rocha[1,2], Shane Baxter[1,2], Dr Monica Furaste Danilevicz[1,2]

Collaborating organisations: [1]UWA; [2]AHRI

Currently, most herbicides are uniformly applied to fields. However, weed detection and targeted control is now possible, due to the rapid advances in digital technology and data science. For example, sensors/ cameras, with associated algorithms to identify weeds, are becoming more common on boom sprayers. This allows individual weeds to be sprayed with herbicide rather than whole fields, which significantly reduces herbicide use and cost to farmers.

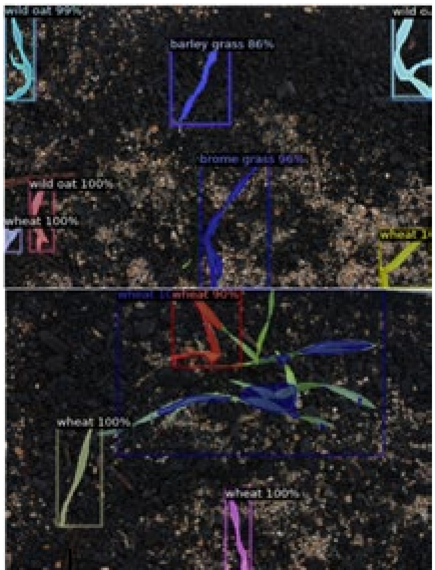
However, in many situations weed detection through computer vision remains a challenging task, due to the complexity of real-world environments and the morphological similarities between weeds and crops, particularly at the early growth stages. The aim of this study was to determine whether deep learning algorithms could differentiate three morphologically similar grass weeds from wheat plants. These weed species were - wild oat (*Avena fatua*), barley grass (*H. glaucum*) and brome grass (*Bromus spp.*) which were seeded in various combinations alongside wheat (*Triticum aestivum* L.) in a glasshouse and a field trial (at Kokeby in WA). A total of 1426 images of the plants were captured at early (tillering) growth stages (GS21 to GS23), using a Canon EOS 7D with a 50mm fixed focal length lens. The camera was placed at two heights above the ground (0.5m and 1.0m) and two angles to the horizontal, either facing directly down (90°) or angled down (60°). The images were then labelled using an annotation tool. Eighty percent of the images (along with data augmentation) were used to train a Detectron2 deep learning model for weed detection. The remaining 20 per cent of the images were used to evaluate the performance of the trained model. Images were resized before model training due to GPU memory limitations, so a more powerful computational platform would be desirable to improve model accuracy.

The images taken in the field resulted in slightly lower average precision (AP) compared with the glasshouse images, likely due to greater diversity in plant appearance/ conditions. The AP of the algorithm to detect weed species decreased for both the 60° and 90° angles when camera height was increased, although less so for the 60° camera angle. The accuracy of prediction decreased on the last date of imaging, hence it was excluded from further analysis, as the plants grew out, leaves on neighbouring plants overlapped (be they wheat or one of the weed species). There was also a high portion of shaded images which diminished the effectiveness of a soil mask to separate plants from background pixels. An artificial light source is a potential solution to reduce shading.

Our model detected 73 per cent of the weeds present in the glasshouse, whether correctly identified by species or not. Considering both crop and weeds, wheat had the highest proportion of plants detected at 63 per cent (termed recall), followed by brome grass (58 per cent), wild oat (56 per cent) and barley grass, which had the lowed proportion of detections (35 per cent). Although barley grass had more plants missed, it had a relatively high rate of precision (correct species identification) at 59 per cent, along with wild oat. Conversely, wheat had the lowest precision at 44 per cent and where wheat was incorrectly identified, it was most often confused with wild oat.

Although more work is required to improve model precision and recall, this study is a first step to detect and differentiate weed species in crops with similar morphology.

This research is supported by UWA.



Comparison of model predictions. The first image shows good predictions with higher intersection over union (IoU), the second image shows poor predictions with lower IoU due to overlaying weeds.

AHRI researchers Drs Qin Yu and Heping Han with former PhD candidate Dr Huan Lu.

Metabolic herbicide resistance to HPPD-inhibiting herbicides in wild radish

Project team: Associate Professor Qin Yu[1,2] (project leader; qin.yu@uwa.edu.au), Dr Huan Lu[3], Yingze Liu[3], Mengshuo Li[3], Professor Sheng Qiang[3], Dr Fengyan Zhou[4], Dr Alex Nyporko[5], Adjunct Professor Steve Powles[1,2]

Collaborating organisations: [1]UWA; [2]AHRI; [3]Nanjing Agricultural University, China; [4]Anhui Academy of Agricultural Science, Anhui, China; [5]Taras Shevchenko National University of Kyiv, Ukraine

Wild radish (*Raphanus raphanistrum*) is a damaging dicot weed infesting crops in Australia. Wild radish is cross pollinated, genetically diverse, and causes crop yield losses even at low densities. Many herbicides are effective on wild radish. However, over-reliance on herbicides has led to multiple resistance evolution in wild radish.

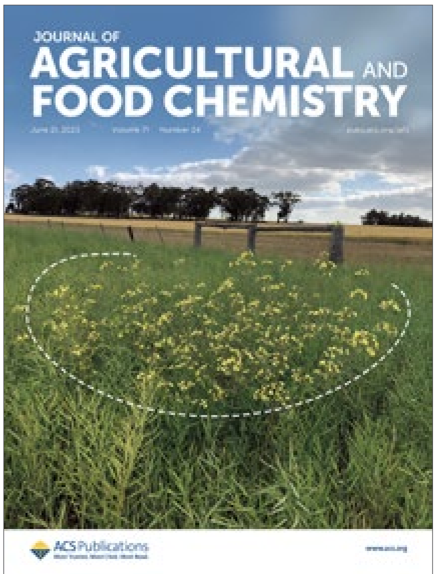
A wild radish population has been recently confirmed to be cross-resistant to Hydroxyphenyl pyruvate dioxygenase (HPPD)-inhibiting herbicides without previous exposure to these herbicides. This cross-resistance is endowed by enhanced metabolism. Our study identified one 2-oxoglutarate/Fe(II)-dependent dioxygenase gene (*Rr2ODD1*) and two P450 genes (*RrCYP704C1* and *RrCYP709B1*), which were significantly higher expressed in R versus susceptible plants. Gene functional characterisation using Arabidopsis transformation showed overexpression of *RrCYP709B1* conferred a modest level of resistance to mesotrione. UPLC-MS/MS analysis showed tissue mesotrione levels in RrCYP709B1 transgenic Arabidopsis plants were significantly lower than that in the wild type. In addition, overexpression of *Rr2ODD1* or *RrCYP704C1* in Arabidopsis endowed resistance to tembotrione and isoxaflutole.

Structural modelling indicated mesotrione can bind to CYP709B1 and be easily hydroxylated to form 4-OH-mesotrione. Although each gene confers a modest level of resistance, overexpression of the multiple herbicide-metabolising genes could contribute to HPPD-inhibiting herbicide resistance in this wild radish population.

This work was published in *Journal of Agricultural and Food Chemistry*. More metabolic genes will be revealed in the future for metabolism-based herbicide resistance in wild radish.

HPPD herbicides have been extremely important for the control of wild radish in Australia, and we are now starting to see resistance emerge to these herbicides. It is amazing that we have this research confirming the resistance mechanism to these herbicides before resistance has become widespread. This will be of enormous help when are faced with more HPPD resistance in the future.

This research is supported by the National Natural Science Foundation of China and the GRDC.



Cover image for the Journal of Agricultural and Food Chemistry showing wild radish infesting canola crop in Western Australia.

Goosegrass infesting rice fields in China.

Genomic insight into glyphosate resistance in goosegrass

Project team: Associate Professor Qin Yu[1,2] (project leader; qin.yu@uwa.edu.au), Dr Chun Zhang[2], Professor Xingshan Tian[2], Nicholas Johnson[3], Dr Nathan Hall[3], Dr Eric Patterson[3]

Collaborating organisations: [1]UWA; [2]Guangdong Academy of Agricultural Science, China; [3]Michigan State University, USA

Goosegrass (*Eleusine indica*) is one of the most economically important weed species in tropical and sub-tropical regions globally, commonly infesting cereals (especially rice), legumes, cotton, vegetable crops, and turf systems. Glyphosate is a non-selective herbicide that targets the protein 5-enolpyruvylshikimate-3-phosphate *synthase* (EPSPS). Decades of using the herbicide glyphosate for goosegrass control has applied enormous selective pressure for glyphosate resistance evolution.

Genomic structural variation (SV) has profound effects on organismal evolution; often serving as a novel source of genetic variation. Gene copy number variation (CNV), one type of SV, has repeatedly been associated with adaptive evolution in eukaryotes, especially with environmental stress. Resistance to glyphosate in goosegrass has evolved through target-site CNV; however, the origin and mechanism of these CNVs remain elusive due to limited genetic and genomic resources.

To study this CNV in goosegrass, we present high-quality reference genomes for glyphosate-susceptible and – resistant goosegrass, fine-assembles of the duplication of glyphosate's target site gene *EPSPS* and reveal a unique rearrangement of *EPSPS* involving chromosome subtelomeres. We have discovered that the *EPSPS* gene in GR *E. indica* has been fused with another part of the genome, inserted in one or more of the subtelomeric regions of the genome, and duplicated an average of 25 times. We hypothesise that after the initial translocation and fusion, *EPSPS* duplication has carried on through unequal crossing over of the subtelomeres on chromosome three and potentially other chromosomes, facilitated by the high frequency of recombination and similarity of the subtelomeric sequences in the distal chromosome ends, which future work could investigate. This discovery adds to the limited knowledge of the importance of subtelomeres as novel variation generators and provides another unique example for herbicide resistance evolution. This work was published in *Nature Communications*.

In addition to glyphosate, goosegrass also has evolved resistance to multiple herbicides including glufosinate and paraquat. The reference genome generated for this species will be used for resistance gene discovery.

This research is supported by the National Science Foundation of China, Michigan State University and the National Science Foundation Research Traineeship Program, and the GRDC.

Wheat streak mosaicdisease infected wheat crop in New South Wales slopes region. The leaves are all dying back due to the disease.

Wheat virus disease research

Project team: Adjunct Professor Roger Jones[1] (project leader; roger.jones@uwa.edu.au), Dr Ian Adams[2], Dr Adrian Fox[2], Dr Ines Vasquez-Iglesias[2], Samuel McGreig[2], Emeritus Professor Adrian Gibbs[3]

Collaborating organisations: [1]UWA; [2]FERA Science Ltd, UK; [3]Australian National University, Canberra; DPIRD

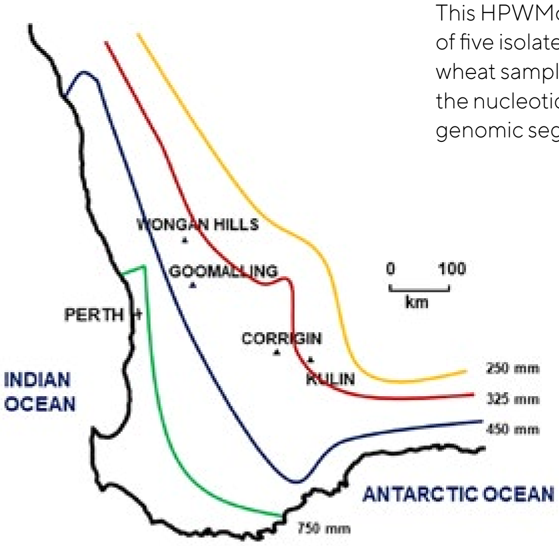
This project arises from the need to study the Wheat Streak Mosaic Disease (WSMD) complex in relation to:

i) Its seed-borne dispersion around the world,
ii) The likely impact of global warming in accentuating the losses its epidemics cause globally, and
iii) Its impact on global food security.

WSMD now occurs in all continents. It has spread to all major grain growing regions of Australia. It has three causal agents, wheat streak mosaic virus (WSMV), High Plains wheat mosaic virus (HPWMoV) and Triticum mosaic virus (TriMV). WSMV and HPWMoV arrived in Australia about 20 years ago. TriMV seems likely to arrive soon. All three viruses are transmitted by the same tiny wheat curl mite (WCM) vector. They often occur together in mixed infection within the same WSMD-affected plant, which enhances the resulting seed yield losses. Because WCM populations increase rapidly under warm growing conditions, global warming is projected to increase WSMV and HPWMoV spread in Australia and the resulting seed yield and seed quality (shrivelled grain) losses from WSMD. HPWMoV was selected for this project's second phase, and a research paper on its phylogenetics was published in 2023.

This HPWMoV study obtained sequences of five isolates from Western Australian wheat samples. Phylogenetic analysis of the nucleotide sequences of the eight genomic segments of these five isolates together with others from Genbank found they formed two lineages, L1 and L2. L1 contained a single isolate the North American Great Plains Region (GPR), and L2 had two unresolved clusters, A and B, made up of isolates from Australia and the GPR. A quarter of the L2B isolate sequences of RNA3 were recombinant, which is unexpected in viruses with negative single-stranded RNA genomes. Phylogenies calculated from the amino acid sequences of HPWMoV's RNA1, RNA2, and RNA3 showed they were closest to those of Palo Verde broom virus. However, its RNA4 was closer to those of Ti ringspot-associated and common oak ringspot-associated viruses, indicating the RNA4 segments of their ancestors reassorted to produce current emaraviruses. To avoid increased yield losses from co-infection, biosecurity measures are advised to avoid HPWMoV introduction, especially to countries where WSMV already occurs.

This research is supported by UWA, the UK Department of Environment Food and Rural Affairs Future Proofing Plant Health Project, the EUPHRESCO VirusCurate project, and DPIRD.



Collection sites in the south-west Australian grain belt where HPWMoV-infected wheat samples were obtained. The grain belt is subdivided into three zones with 250–325mm (low), 325–450mm (medium), and 450–750mm (high) of rainfall per year.

Potato plant infected with potato virus S showing leaf mosaic symptoms.

Sequencing historical crop virus isolates

Project team: Adjunct Professor Roger Jones[1] (project leader; roger.jones@uwa.edu.au), Dr Topkaya Ş[2], Dr Çelik A[3], Dr Santosa AI[4]

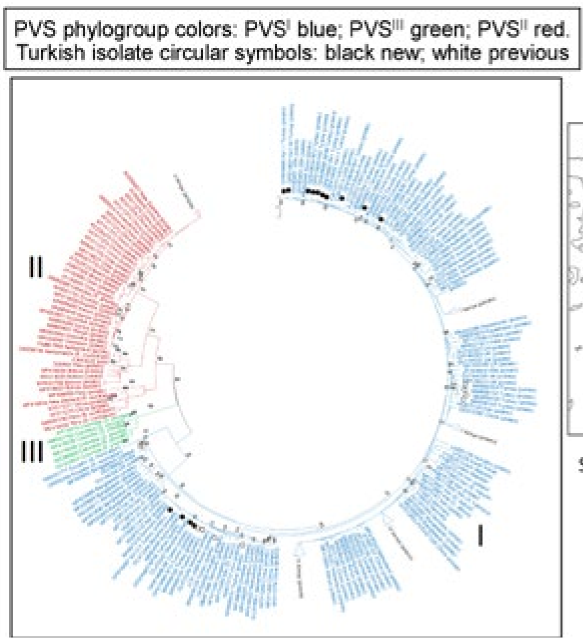
Collaborating organisations: [1]UWA; [2]Tokat Gaziosmanpasa University, Turkey; [3]Bolu Abant Izzet Baysal University, Turkey; [4]Universitas Gadjah Mada, Indonesia

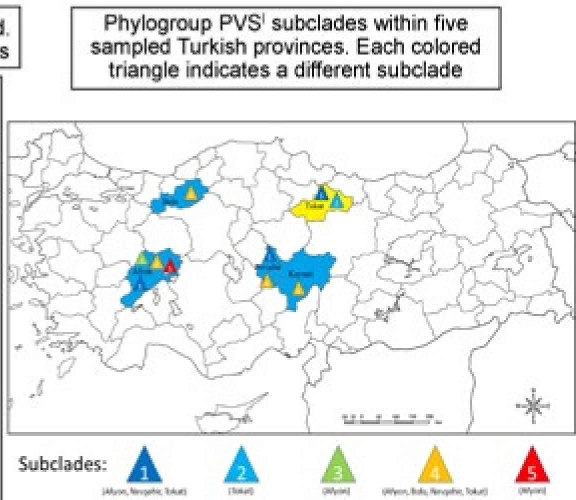
Potato is now the world's third most important staple food crop. Potato virus S (PVS) commonly infects it worldwide including in Australia. An earlier phylogenetic study involving IOA demonstrated the impacts of globally significant historical events, such as the arrival of Europeans in South America and the European potato famine, upon PVS evolution.

This follow-up study involving collaboration with Turkish scientists further improved understanding of PVS dissemination worldwide by comparing new PVS sequences from different Turkish provinces with all PVS sequences from GenBank. Renaming it's phylogroupings as PVSI, PVSII and PVSIII was supported by the worldwide distribution of PVSI and PVSII, and the recent spread of PVSII from potato's Andean domestication centre to East Africa and East Asia.

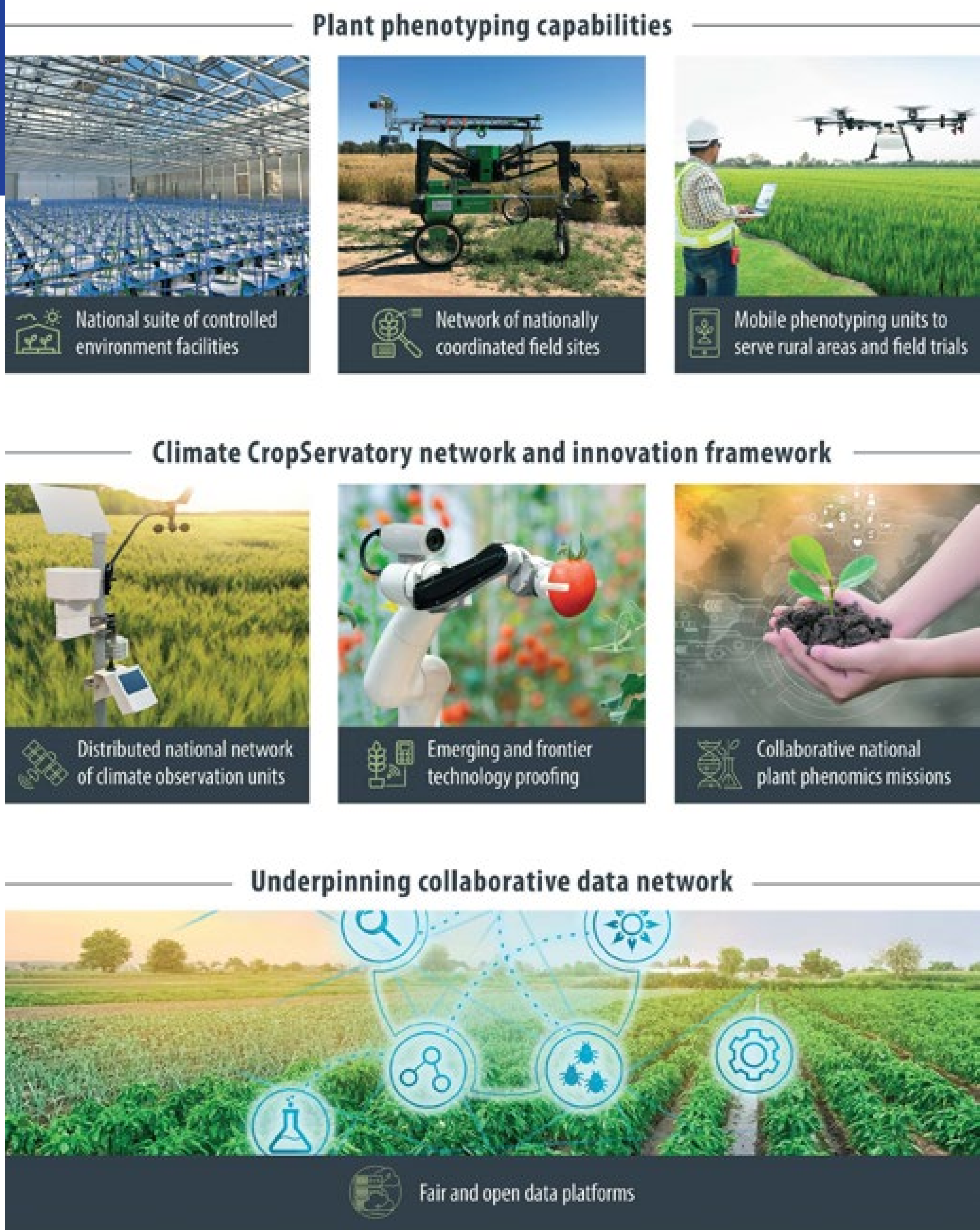
Genetic variation was considerable within phylogroups PVSI and PVSII, and both were expanding, whereas PVSIII had low variation and was undergoing balancing selection. Presence of Turkish sequences within phylogroup PVSI subclades 1–5 indicated two early and three recent PVS introductions. Phylogroup PVSII poses a biosecurity threat to countries without it. This seems likely via distribution of potato germplasm for potato breeding and the international seed potato tuber trade.

This research is supported by UWA, Tokat Gaziosmanpasa University, Bolu Abant Izzet Baysal University, and Universitas Gadjah Mada.





Distribution of five different potato virus phylogroup PVSI subclades within the five Turkish provinces sampled. Each coloured triangle indicates a different PVSI subclade. On the map, blue colour identifies the four Turkish provinces where potato leaf samples were collected in this study, and yellow colour the Turkish province sampled previously.



The Australian Plant Phenomics Network, comprising a national suite of controlled environment facilities, coordinated field sites, mobile phenotyping units, climate observation and data networks.

The Australian Plant Phenomics Network: WA Node

Project team: Associate Professor Nicolas Taylor[1] (project leader; nicolas.taylor@uwa.edu.au), Associate Professor Nik Callow[1]

Collaborating organisations: [1]UWA; The University of Adelaide; Australian National University, Canberra; Charles Sturt University, NSW; DPIRD; La Trobe University, Victoria; The University of Queensland, Queensland; The University of Sydney, NSW; Western Sydney University, NSW

The Australian Plant Phenomics Network (APPN), Australia's national plant phenomics research infrastructure, received $60 million in core funding in 2023 to expand its world-leading network of facilities across Australia and accelerate the development of improved crops to 2028. The $60 million NCRIS investment is planned to be matched by contributions from university partners, state governments and industry for a total investment of nearly $135 million.

The funds will expand APPN's national network to nine partner nodes, including UWA and DPIRD, and provide a greater diversity of controlled growth environments and field phenotyping facilities. Plant phenomics is a rapidly developing field that combines biology, engineering, robotics and data to measure how plant genetics are expressed under different growing conditions. Plant breeders and scientists can use phenotyping to accelerate their understanding and development of higher yielding and more nutritious crop varieties, greater resilience to climate change, and more sustainable agricultural practices.

This research is supported by UWA, the National Collaborative Research Infrastructure Strategy, DPIRD, and the WA Department of Jobs, Tourism, Science and Innovation.

Sunset at UWA Farm Ridgefield in West Pingelly.
Credit: Dr Zoey Durmic

2

Sustainable Animal Production Systems

Research undertaken in the Sustainable Animal Production Systems theme has contributed to the nexus between crop/pasture and livestock production, conducted in close cooperation with other national and international Research, Development, Extension and Adoption partners.

This theme encompasses the sustainable contribution of livestock industries to global food supply. The focus is on resolving five key problems. These are:

1) The consumption of human food by livestock,
2) Livestock species and genotypes that are poorly adapted to the local environment,
3) Poor animal health and welfare resulting in sub-optimal productivity,
4) Provision of adequate animal nutrition, and
5) The environmental footprint.

Mixed crop-pasture systems in the agricultural region of WA are largely sheep-based, with a smaller cattle component. The feed base is dominated by the use of annual pastures, predominantly subterranean clover. It is essential that grazing systems are sustainable if they are to continue to support animal-production systems. UWA has a current focus on development of phosphorus efficient pastures that can maintain productivity on lower soil phosphorus levels. Within the system, the interaction of pasture and crop is critical to the management of weeds, including herbicide resistant weeds, because within the pasture phase, offers a clear pathway that can supplement options to improve sustainability of cropping. Aspects of efficient nutrition use and disease control also show promise to alleviate issues that are problematic in the cropping phase.

Theme Leaders

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ZNE-Ag CRC COO Georgia Sheil, CFO Riaan Retief, Communications Lead Rachel Buchanan, CEO Richard Heath, Executive Assistant Annie Cox., and Producer Demonstration Site Lead Michael Taylor. Credit: Richard Heath

The logo for CRC for Net Zero Emissions from Agriculture.

Zero Net Emissions from Agriculture Cooperative Research Centre

Project team: Professor Philip Vercoe[1], Professor Marit Kragt[1], Richard Heath[2] (project leader; richard.heath@uq.edu.au), Georgia Sheil[2], Riaan Retief[2], Michael Taylor[2], Rachel Buchanan[2], Annie Cox[2], Professor Ben Hayes[2], Vicki Lane[3], Professor Richard Eckard[4], Associate Professor Janelle Wilkes[5]

Collaborating organisations: [1]UWA; [2]The University of Queensland; [3]Queensland Department of Agriculture and Fisheries; [4]The University of Melbourne; [5]The University of New England; Cooperative Research Australia

There are more than 70 collaborating organisations nation-wide actively involved in this CRC. The above organisations only reflect the project leads.

In December 2023, a new national centre to transition Australian agriculture to net-zero, healthy, resilient and profitable food systems secured $300 million in funding over 10 years. UWA is collaborating on The Zero Net Emissions from Agriculture Cooperative Research Centre (CRC), which will be led by the University of Queensland. The national collaboration includes a Federal Government contribution of $87 million to create impactful research on sustainable agriculture and drive real-world change.

The UWA Institute of Agriculture Associate Director Professor Philip Vercoe will lead the Livestock program and Associate Professor Marit Kragt is the research lead for the Value from Net Zero program. The Centre aims to drive industry, community and government action to achieve zero net emissions from agriculture from 2040, and below zero net emissions by 2050. Agriculture directly contributes to 14 per cent of Australia's national emissions.

The Centre's goal is to ensure Australia's agricultural industries keep growing, while they simultaneously achieve Zero Net Emissions by 2040 and exceed international emissions reduction targets by 2050.

Emissions reduction was often seen as a cost burden that created a trade off against economic imperatives that drove productivity, profitability, growth and asset building. The Centre will harness and coordinate opportunities for rapid research, development and adoption of science and technology-led solutions, driven by our industry and government partners.

This research is supported by UWA, Cooperative Research Australia, The University of Queensland, Queensland Department of Agriculture and Fisheries, The University of Melbourne, and The University of New England.

Dr Suyog Subedi delivering feed containing Agolin® Ruminant to grazing sheep.

Sheep accessing the GreenFeed unit to measure their methane at UWA Farm Ridgefield.

Methane Emissions Reduction in Livestock

Project team: Dr Zoey Durmic[1] (project leader; zoey.durmic@uwa.edu.au), Dr Stephanie Payne[1], Dr Suyog Subedi[1], Dr Joy Vadhanabhuti[1], Angad Singh[1], Sam Lloyd[1], Hatem Al-Khazraji[1], Jamie King[1], Montana Walsh Baddeley[1], Janet Kok[1], Nathan Phillips[2]

Collaborating organisations: [1]UWA; [2]Fixd; Australian Government

Can a common feed additive used to improve appetite in sheep – based on essential oils from coriander and wild carrot – also reduce the methane that ruminants produce? A UWA research team, led by Dr Zoey Durmic, are developing feeds and feed supplement solutions to lower methane emissions from livestock. The Methane Emissions Reduction in Livestock (MERiL) project, based at UWA Farm Ridgefield, is evaluating if the feed additive Agolin® Ruminant can lead to potential benefits of methane mitigation, sheep health, performance, and welfare.

Successful outcomes of this project will contribute to the development of sustainable practices for extensively grazed livestock across Australia, promoting carbon neutrality in the sheep industry and ensuring market access for environmentally certified products like wool and sheep meat.

Additionally, the study will provide valuable data for future regulatory methods and offer producers clear options for methane mitigation strategies. The knowledge gained can be applied to other antimethanogenic additives, fostering a long-term reduction in the greenhouse gas footprint of the Australian sheep industry. Overall, this research will advance our understanding of plant-based additives for methane mitigation across the broader Australian livestock sector.

The preliminary study will include feed additive being delivered to sheep in pen trial via loose lick, pellets or grain supplements. In 2024, the project will progress to a larger trial to deliver the additive in practical, year-round grazing conditions.

This research is supported by UWA and a MERiL grant from the Australian Government and industry partners.

Sheep are fitted with GPS, accelerometers, proximity sensors and ruminal temperature loggers for five to six weeks of the mating period.

Shade and Shelter Project

Project team: Professor Shane Maloney[1] (project leader; shane.maloney@uwa.edu.au), Associate Professor Dominique Blache[1], Dr Kelsey Pool[1], Dr Luoyang Ding[1], Associate Professor Serina Hancock[2], Dr Lea Labeur[2], Georgia Welsh[2], Jarryd Krog[2], Dr Hayley Norman[3], Matt Wilmott[3]

Collaborating organisations: [1]UWA; [2]Murdoch University; [3]CSIRO; NSW DPI

The Shade and Shelter Project encompasses both the UWA-led heat stress and sheep reproduction project and the Murdoch University-led project around edible shelter to improve lamb survival.

This project in heat stress aims to quantify the effects of heat events on sheep reproduction, thermoregulatory capacity, behaviour and wellbeing through long term-data collection while the sheep will be exposed to a range of climatic conditions in diverse production settings.

The edible shelter component investigates the impacts of different types of edible shelter on the physiology, behaviour, welfare and survival of lambs, along with the nutritional benefits of the feedbase in mixed farming enterprises.

Outcomes of this research may be used to inform management strategies to;

i) Minimise the impact of heat stress on reproductive performance and animal welfare, and
ii) Improve lamb survival by improving the lambing environment.

The outcomes will also help to understand animal behaviour and resource use in response to a changing environment.

The research team acknowledges the producers who have contributed to this project by way of volunteering their sheep for instrumenting and monitoring, including Simon Tighe at Cuttening Farm near Kellerberrin, Michael and Blair Humphry at Pankee Farm near Moora, Zac Roberts on Strathmore near Dandaragan, and Tom Foulkes-Taylor on Yuin Station in the Lower Murchison.

This research is supported by UWA and Meat & Livestock Australia.

Sample testing underway at UWA Farm Ridgefield.

PhD candidate Michael Young visiting farms in the WA wheatbelt.

Identifying high value tactical livestock decisions on a mixed enterprise farm in a variable environment

Project team: Michael Young[1] (project leader; youngmr44@gmail.com), Professor Philip Vercoe[1], Professor Ross Kingwell[1,2]

Collaborating organisations: [1]UWA; [2]Australian Export Grains Innovation Centre (AEGIC); DPIRD

Australia is renowned for its climate variation including years with drought and years with floods, which result in significant production and profit variability. Accordingly, to maximise profitability, dryland farming systems need to be dynamically managed in response to the unfolding weather conditions.

The aim of this work was to identify and quantify optimal tactical livestock management for different weather-years. This study employs AFO, a whole farm optimisation model to analyse a representative mixed enterprise farm located in the Great Southern region of Western Australia. Using this modelling approach, we investigated the economic significance of five key livestock management tactics. These include, sale timing, pasture area adjustments, rotational grazing, crop grazing and animal nutrition adjustments.

The results show that, on dryland mixed enterprise farms in the Great Southern region of Western Australia, short-term adjustments to the overall farm strategy in response to unfolding weather condition increases expected profit by approximately 16 per cent. Individually each tactic was worth between $7,700 and $53,200 on average per year. Furthermore, the paper outlines several complexities that farmers must consider when implementing tactics.

The financial gains from short-term tactical management underscore the importance of developing tactical management skills. The study advocates for the acquisition of tactical skills, promoting adaptability in the face of climate uncertainties. These insights contribute to a more resilient and profitable agricultural landscape. The study highlights the economic value of dynamic livestock management in response to climate variations, offering farmers in the Great Southern region profitable management strategies for sustainable farming.

This research is supported by UWA and Sheep Industry Business Innovation through DPIRD.

Sheep about to be pregnancy scanned.

Collaborative research in improving sheep productivity with Chinese universities

Project team: Dr Shimin Liu[1] (project leader; shimin.liu@uwa.edu.au), Huimin Niu[2], Anmin Lei[2], Huibin Tian[2], Weiwei Yao[2], Ying Liu[2], Cong Li[2], Xuetong An[2], Xiaoying Chen[2], Zhifei Zhang[2], Jiao Wu[2], Min Yang[2], Jiangtao Huang[2], Fei Cheng[2], Jianqing Zhao[2], Jinlian Hua[2], Jun Luo[2], Xue'er Du[2], Zhijie Cui[2], Rui Zhang[2], Keliang Zhao[2], Lamei Wang[2], Junhu Yao[2], Chuanjiang Cai[2], Yangchun Cao[2]

Collaborating organisations: [1]UWA; [2]Northwest A&F University; Inner Mongolian Academy of Agricultural and Animal Husband Sciences

Collaboration with Inner Mongolian Academy of Agricultural and Animal Husband Sciences and Northwest A&F University was carried out to improve profitability of sheep production. The activities include organising online seminars presented by Australian academics and farmers, attending online meetings, and contributing to joint publications.

Greta Bradford and Dr Dawson Bradford (IOA Industry Advisory Board member), with Dr Shimin Liu (middle) visit a sheep breeding farm in Inner Mongolia, China.

Two joint publications were published in 2023. The first article, published in the *International Journal of Molecular Sciences*, concluded that the fatty acid Stearoyl-CoA desaturase 1 (Scd1) gene is essential to maintain healthy development of embryos by regulating energy support. Scd1knockout arrested the mouse embryo development, resulting in a lower blastocyst rate and smaller litter size. The effects were mediated by lipid droplet content and the RPs-Mdm2-P53 pathway, which activated apoptosis genes and caused ICM stemness potential to be lost. The effects of the Scd1 gene in blastocyte implantation, embryo development, and fetus growth cannot be ruled out and need to be investigated. In addition, studies on the effect of this gene on embryonic pluripotency will be carried out subsequently.

In the second publication, the research team investigated the effects of rumen-protected choline (RPC) and rumen-protected nicotinamide (RPM) on liver metabolic function based on transcriptome in periparturient dairy cows. Ten healthy Holstein dairy cows with similar parity were allocated to RPC and RPM groups (n = 5). The cows were fed experimental diets between 14 days before and 21 days after parturition. The RPC diet contained 60 g RPC per day, and the RPM diet contained 18.7 g RPM per day. Liver biopsies were taken 21 days after calving for the transcriptome analysis. A model of fat deposition hepatocytes was constructed using the LO2 cell line with the addition of non-esterified fatty acids (NEFA) (1.6mmol/L), and the expression level of genes closely related to liver metabolism was validated and divided into a choline group (75μmol/L) and a Nicotinamide group (2mmol/L).

Overall, the study showed that RPC plays a prominent role in liver metabolism by regulating metabolic processes such as fatty acid synthesis and metabolism and glucose metabolism. Yet, RPM is more involved in biological processes.

This research is supported by UWA, the Inner Mongolian Academy of Agricultural and Animal Husband Sciences, and Northwest A&F University.

Investigating the role of blow fly olfaction in flystrike in sheep

The sheep blow fly, Lucilia cuprina, showing the club-shaped antennae. Credit: Minibeast Wildlife

Project team: Emeritus Professor Graeme Martin[1] (project leader; graeme.martin@uwa.edu.au), Dr Guanjie Yan[2], Dr Tony Schlink[1], Dr Shimin Li[1], Adjunct Professor Johan Greeff[1], Associate Professor Gavin Flematti[1]

Collaborating organisations: [1]UWA; [2]Nanyang Normal University, China; DPIRD

Breech flystrike is a painful, debilitating and potentially lethal disease caused by the larvae of the blow fly *Lucilia cuprina* (image 1), and, despite many years of research, it remains a serious financial and animal welfare issue for the Merino sheep industry in Australia. The common methods of prevention – insecticides, crutching and 'mulesing' – are problematical so alternative approaches are needed.

Breeding for resistance to breech strike is a fundamentally attractive proposition, but the trait itself is difficult and expensive to quantify in large numbers of sheep in extensive production systems. Several indirect traits are correlated with susceptibility to flystrike, but a large proportion of the variation in susceptibility remains unexplained.

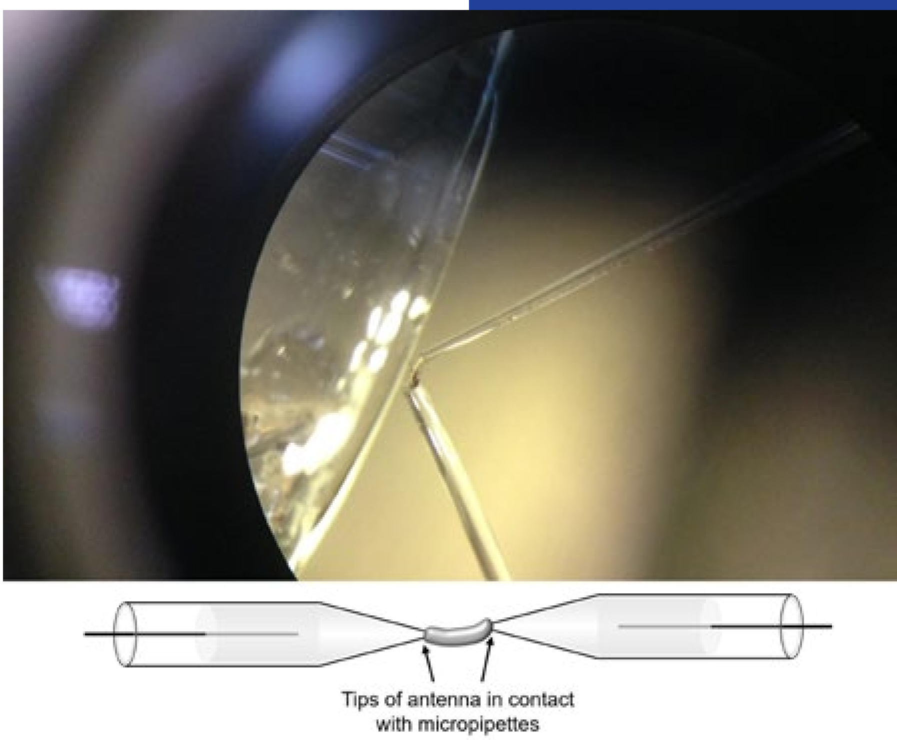
The common thread through those indirect traits is odour, so we turned our attention to the biology of insect olfaction. *L. cuprina* uses odours to detect and locate potential hosts over long distances, to guide orientation and landing behaviour, and to select egg-laying sites. Preliminary studies showed that we could use flies that had been reared in the laboratory, and that we needed to work with female flies that were carrying eggs.

We then used a combination of gas chromatography-mass spectrometry (GCMS) with electroantennographic detection (EAD), to identify odouriferous compounds from sheep that the antenna of *L. cuprina* can detect (image 2). The next step was to determine whether the identified compounds were attractive or repulsive, using a behaviour test. We observed that L. *cuprina* was attracted by several compounds in Merino wool, including octanal, nonanal and dimethyl trisulphide (DMTS).

We also found that the wool levels of octanal and nonanal are heritable in Merino sheep, suggesting that these compounds might be useful as traits in selection for flystrike-resistance. Another possibility is that these olfactory-active compounds might guide efforts to modify the genome of sheep, or perhaps even *L. cuprina.*

Success in these endeavours could save as much as $200 million per year for the Australian Merino-based industries, whilst also improving the image of wool in world markets.

This research is supported by UWA, the Australian Wool Innovation, DPIRD, and the Scholarship Council – People's Republic of China.



The antenna is detached from the head of the fly and each end is connected to an electrode. Test gases are first passed over a gas chromatography column, then via a 'Y' tube that divides the gas steam into two, one targeting the antenna and the other going to the mass spectrometer. We align the molecule that the antenna can 'smell' with a chemical signature that allows us to identify the molecule. Credit: Dr Guanjie Yan

Revealing the secret life of worms in the gut of sheep

Project team: Dr Erwin Paz[1] (project leader; erwin.pazmunoz@uwa.edu.au), Dr Shamshad Ul Hassan[1], Dr Eng Guan Chua[1], Dr Alfred Chin Yen Tay[1], Adjunct Professor Johan Greeff[1], Dr Dieter Palmer[2], Dr Olga Dudchenko[4,5], Dr Erez Lieberman Aiden[5,6], Dr Carolina Cheuquemán[7], Dr Shimin Liu[1], Associate Professor Peta Clode[1], Emeritus Professor Graeme Martin[1], Associate Professor Parwinder Kaur[1]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]Broad Institute of MIT and Harvard, Cambridge UK; [4]Baylor College of Medicine, USA; [5]Rice University, USA; [6]Shanghai Tech University, China; [7]Universidad del Alba, La Serena, Chile

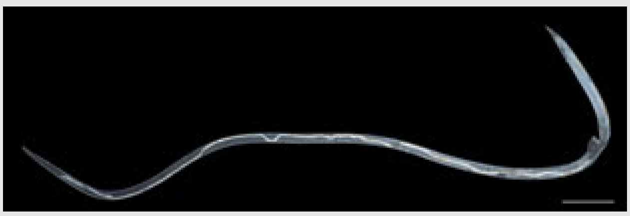
Gastrointestinal helminths (worms) are a global problem that affects the health of livestock and humans. One of the major helminths in sheep, *Teladorsagia circumcincta*, reduces weight gain and causes diarrhoea – in some cases, it kills young animals. Control strategies have relied heavily on the use of anthelmintic medication but, unfortunately, *T. circumcincta* has developed resistance.

Our research has been approaching at this problem in two ways.

The first was to provide a high-quality, chromosome-length, genome assembly for *T. circumcincta* – by understanding the genes, we should be able to identify key determinants of the pathophysiology of infection and the host-parasite interaction, thus accelerating the discovery of new strategies for controlling the parasite, such as novel vaccine targets and drug candidates. We therefore 'polished' the existing draft genome assembly with sequencing data generated using the chromosome conformation, capture-based, *in situ* 'Hi-C' technique. The outcome was six chromosome-length scaffolds with length ranging from 66.6 Mbp to 49.6 Mbp, with 35 per cent fewer sequences and thus a smaller size than the original draft genome. We also gained a more complete proteome.

Secondly, the microbiome inside the gut of the worm. These days, 'gut health' is a highly topical area of research in humans and animals, but no-one has considered the microbiome in the gut of helminths. Could the microbiome in the worm intestine provide insights into the survival of the parasite, as well as the health of the host? We therefore described the intestinal microbiome of *T. colubriformis* that had been collected from the duodenum of sheep and compared it with the duodenal microbiome of the host sheep so we could identify species that did not originate from the worm's environment. The bacterial species in the gut of the parasite and the gut of the host differed in diversity and ecological composition. Differential abundance analysis (16S rRNA) showed that the worm had a significant presence of *Mycoplasmoides* and *Stenotrophomonas*, whereas the sheep did not. Additionally, we found *Aeromonas caviae* and *Aeromonas hydrophila* in the worm gut. It is clear that the intestine of *T. colubriformis* carries a specific bacterial community that might be related to the long-term survival of the worm in the digestive system of the host.

This research is supported by UWA, The University of Agriculture Faisalabad, DNA Zoo Consortium, Welch Foundation, McNair Medical Institute Scholar Award, NIH Encyclopedia of DNA Elements Mapping Center Award, US-Israel Binational Science Foundation Award, Behavioral Plasticity Research Institute, NSF Physics Frontiers Center Award, NIH CEGS and the Western Australian Meat Marketing Company.



A female *Teladorsagia circumcincta*, a worm that lives in the gut of the sheep. Credit: Associate Professor Peta Clode

Perspective: Science and the future of livestock industries

Project team: Emeritus Professor Graeme Martin[1] (project leader; graeme.martin@uwa.edu.au)

Collaborating organisation: [1]UWA

Emeritus Professor Graeme Martin at UWA Farm Ridgefield.

Emeritus Professor Graeme Martin was invited to present keynote papers at two meetings held at the Shaheed Benazir Bhutto University of Veterinary and Animal Sciences in Pakistan:

i) First International Symposium on Animal Welfare and One Health (May 2022); and
ii) Animal Production and Food Security – Identifying Challenges and Finding a Way Forward (April 2023).

Emeritus Professor Martin decided to present a positive paper on the contribution of science to the future of food produced from ruminant livestock. In the second meeting, he shared the platform with Frank Mitloehner (University of California, USA) and Fred Leroy (Universiteit Brussel, Belgium). Their recent work has been instrumental in changing the nature of the international discussion around greenhouse gas emissions from ruminants, and the role of animal-sourced foods in nourishing humanity.

Livestock industries have been forced to respond to major pressures from society since the 1990s, particularly with respect to methane emissions and animal welfare. These challenges are exacerbated by the inevitability of global heating and the effects it will have on livestock productivity. The same challenges also led to questions about the value of animal-sourced foods for feeding the world.

The industries and the research communities supporting them are rising to meet those challenges. For the ruminant methane problem, we can now envisage solutions, and there is a 'win-win' situation because those solutions will also improve the efficiency of meat and milk production. Animal welfare is a complex mix of health, nutrition and management. With respect to health, the 'One Health' concept is offering better perspectives, by taking on board zoonotic diseases so the management of health in humans and livestock is coordinated. In addition, major livestock diseases, such as helminth infection, these days compounded by resistance against medication, are being resolved through genetic selection. With respect to nutrition and stress, 'fetal programming' and the epigenetic mechanisms involved is a very 'hot' area of research, with intriguing possibilities for improving productivity. Obviously, stress needs to be minimised, including stress caused by extreme weather events, and solutions are emerging through technology that reveals when animals are stressed, and through an understanding of the genes that control susceptibility to stress. Indeed, discoveries in the molecular biology of all of the physiological processes that underpin 'clean, green and ethical' management will greatly accelerate genetic progress and contribute to genomic solutions.

Overall, the global context is clear – animal-sourced food is an important contributor to the future of food for humanity, but the responses of livestock industries must involve local actions that are relevant to geographical and socio-economic constraints. The questions are the same for both developing and developed countries, but the solutions will be different.

This research is supported by UWA and Australian Wool Innovation.

The ram effect: Is it only useful in Australia, or can it be extended to pre-pubertal and mature ewes in the USA and Mexico?

Project team: Emeritus Professor Graeme Martin[1], Dr César Rosales-Nieto[2] (project leader; cesar.rosales@txstate.edu), Associate Professor Andrew Thompson[3], Dr Venancio Cuevas-Reyes[4], Dr Luisa Hérnandez-Arteaga[5], Dr Richard Ehrhardt[6], Dr Almudena Veiga-Lopez[6], Adjunct Professor Johan Greeff[1,7]

Collaborating organisations: [1]UWA; [2]Texas State University, USA; [3]Murdoch University; [4]Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Campo Experimental Valle de México; [5]Universidad Autónoma de San Luis Potosí, México; [6]Michigan State University, USA; [7]DPIRD

The ram effect (or 'teasing') is common practice in Australia and is critical for Merino ewes bred before February. It allows control of the time of lambing and allows synchronised births in the flock. It can also increase fertility, prolificacy, and reproductive rate (number of fetuses per 100 ewes exposed to fertile rams).

We analysed records from 59,716 ewes collected over 34 years (1986-2020) from seven genotypes: Border Leicester, Composite (crossbred), Dorset, Merino, Dorset x Polypay, Rambouillet, and White Suffolk. The data also included nulliparous young ewes (mated at age eight months) and adult parous ewes. Vasectomised rams were used to stimulate 20,632 ewes before a mating period that lasted two or three oestrous cycles, and the outcomes were compared with those from 39,084 ewes that had not been stimulated. Most of the data were from experiments in Australia, but some were from Mexico and the USA.

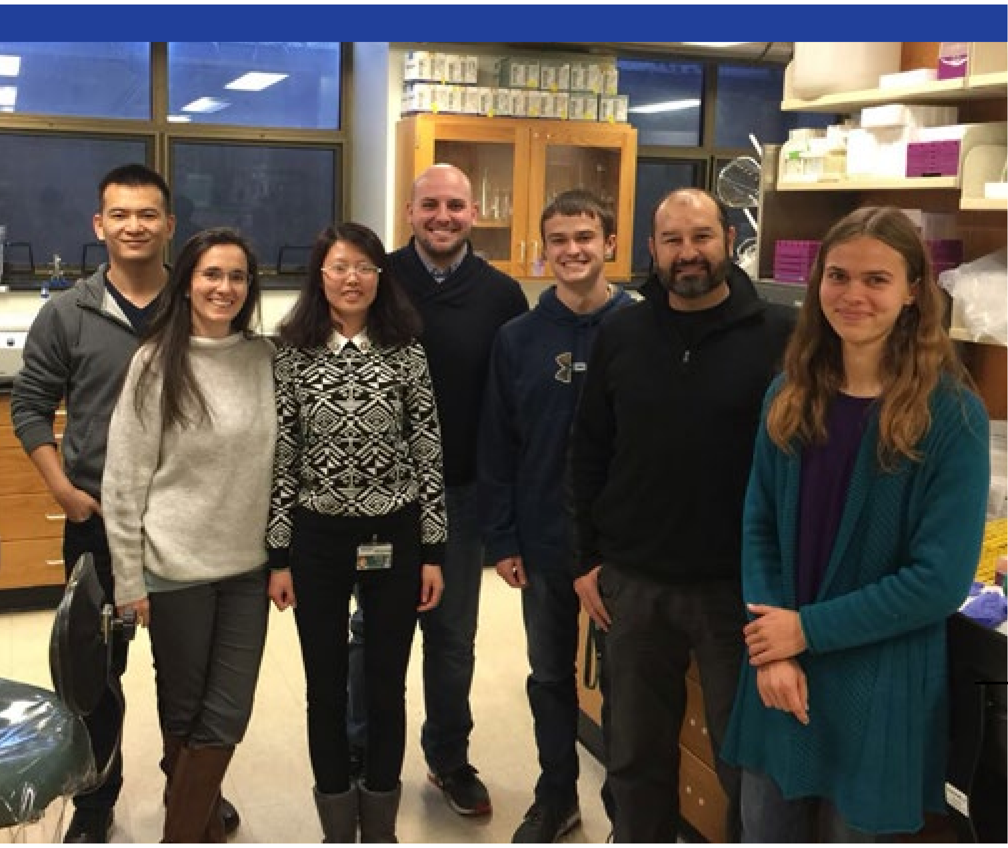
The results: independently of genotype, teasers significantly advanced the average conception date by eight days for young ewes, and by one day for adult ewes. Teasers also significantly increased the proportion of ewes that conceived in their first cycle by 33 per cent for young ewes and by six per cent for adult ewes. For the cycle of conception, two interactions were highly significant: teasing x age at mating and teasing x live weight at mating. Teasing improved fertility in both adult ewes (100 per cent vs 89 per cent) and young ewes (78 per cent vs 81 per cent). Teasing increased the number of young ewes (42 per cent vs 11 per cent) and adult ewes (17 per cent vs 3 per cent) that conceived multiple fetuses in the first 17 days of the mating period.

The reproductive rate was improved by teasing in young ewes (129 per cent vs 135 per cent) but not in adult ewes (120 per cent vs 122 per cent). When all animals for all breeds were included in the analyses, there were statistically significant improvements in fertility, prolificacy, and reproductive rate as age and live weight increased at mating.

Can 'teasing' be used in other breeds and in other parts of the world? The answer is 'yes' judging by all indications from this analysis. Certainly, we have provided enough evidence for people to test the idea further.

We conclude that, independently of genotype, utilising the male stimulus before the mating period reduces the time to conception and improves reproductive performance in both young and adult ewes.

This research is supported by UWA.



One of the sheep teams investigating the value of 'teasing' for managing sheep reproduction. Second from left: Dr Almudena Veiga-Lopez, and second from right: Dr César Rosales-Nieto (former UWA PhD student).

Raising rare breed livestock: New perspectives on domestication, extinction and meat in the Anthropocene

Project team: Dr Catie Gressier[1] (project leader; catie.gressier@uwa.edu.au), Tammi Jonas[1], Dr Domenico Volpicella[1]

Collaborating organisation: [1]UWA

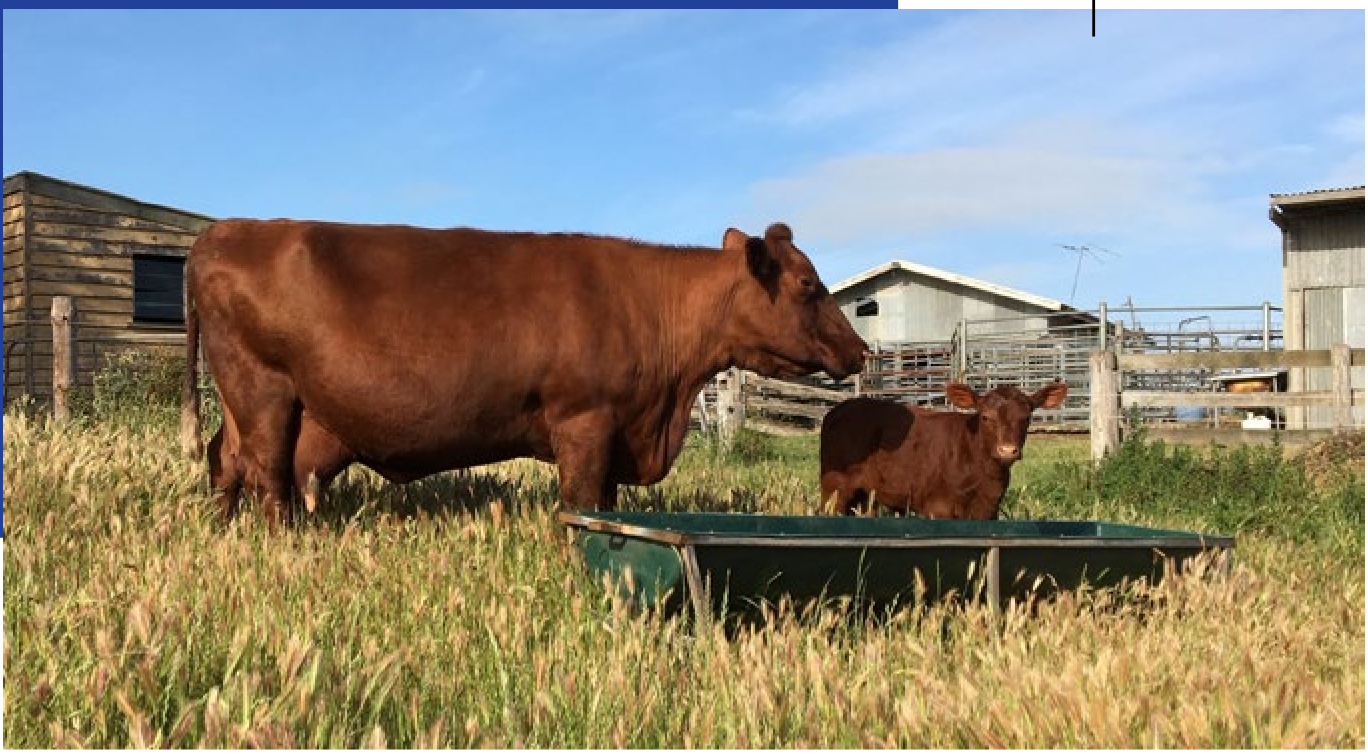
Dr Catie Gressier and rare Elliottdale sheep.

Agrobiodiversity is critical to food security, yet for the past half century, livestock breed and bloodline diversity have decreased at an alarming rate. This project is advancing knowledge of rare and heritage breed farming and conservation and raising awareness of the value of biodiversity at the genetic, species and ecosystem levels.

In 2023, the focus has been on writing up findings, with the project coming to its end. Both Domenico Volpicella and Tammi Jonas submitted their PhD theses to high praise from their respective examiners. Domenico's degree has now been conferred for his research exploring the principles and practices of degrowth through the lens of heritage breed poultry breeding. Tammi Jonas' soon-to-be finalised thesis by publication examining Australia's new peasantry and the agroecological transition is constituted by journal articles now published. The project lead, Dr Catie Gressier, published three articles from the project in her co-edited Special Issue in *Anthropology Today,* along with an article in *Arcadia,* and a book chapter in *Nurturing Alternative Futures.* The project's findings are forthcoming in her book *Saving Heritage Breeds: A Love Story,* from UWA Publishing.

This research is supported by UWA and the Australian Government through the ARC Discovery Project scheme.

An 18-year-old Red Poll and calf.



Brad Wintle and Associate Professor Phillip Nichols in the field. Breeders seed increase at Manjimup of a new ALBA-bred Persian clover (code-named ALBA-Maj23).

Annual Legume Breeding Australia

Project team: Associate Professor Phillip Nichols[1] (project leader; phillip.nichols@uwa.edu.au), Bradley Wintle[2], Professor Megan Ryan[1], Dr Judith Lichtenzveig[1], Dr Maria Pazos-Navarro[1]

Collaborating organisations: [1]UWA; DLF Seeds

Annual Legume Breeding Australia (ALBA) is a Joint Venture between UWA and the pasture seed company, DLF Seeds. ALBA aims to breed improved cultivars of annual pasture legumes for farmers in southern Australia and other international markets. Key species include subterranean clover (sub clover) (*Trifolium subterraneum*), balansa clover *(T. michelianum*), Persian clover (*T. resupinatum*) and arrowleaf clover (*T. vesiculosum*).

Breeding highlights include commercial seed production of three new ALBA sub clover cultivars (Edison, Franklin and Carver). Stage 2 trials continued of elite early flowering sub clover breeding lines at the UWA Farm Ridgefield and other low rainfall sites across southern Australia, while new trials of elite midseason sub clover lines were sown across southern Australia in 2023.

Breeders seed was also produced of new late flowering balansa clover and Persian clover cultivars in 2023, while final selections were made for new midseason balansa clover and arrowleaf clover cultivars that will undergo Breeders seed increase in 2024.

This research is supported by UWA and DLF Seeds.

Commercial seed production of the new ALBA sub clover cultivar, Franklin at Kybybolite, South Australia.

Several dung beetles found among soil dug up on-farm. Credit: Matt Beaver

The winter-active Bubas Bison dung beetle. Credit: Matt Beaver

Dung beetles increase plant growth: A meta-analysis

Project team: Daniel Anderson[1] (project leader; daniel.anderson@research.uwa.edu.au), Dr Jacob Berson[1], Professor Raphael Didham[1], Professor Leigh Simmons[1], Associate Professor Theodore Evans[1]

Collaborating organisations: [1]UWA; Meat & Livestock Australia (MLA)

The ecosystem services provided by dung beetles are well known and valued. Dung beetles bury dung for feeding and breeding, and it is generally thought that the process of burying dung increases nutrient uptake by plant roots, which promotes plant growth. Many studies have tested the effects of dung beetles on plant growth, but there has been no quantitative synthesis of these studies.

For this study, the researchers used a multi-level meta-analysis to estimate the average effect of dung beetles on plant growth and investigate factors that moderate this effect. They identified 28 publications that investigated dung beetle effects on plant growth. Of these, 24 contained the minimum quantitative data necessary to include in a meta-analysis.

Overall, they found that dung beetles increased plant growth by 17 per cent. When dung beetles accessed dung, plant weights generally increased more than plant lengths. Nutrients from buried dung appeared to be incorporated into plant shoots, allowing for thicker leaves with greater photosynthetic capability, the process by which plants convert light into chemical energy to fuel their growth. Additionally, the recycled nutrients might have caused a proliferation of root hairs, which would allow for greater nutrient uptake and take away the need for investment in longer plant roots.

The research team also found that plant growth was greater when more beetles accessed dung, likely because it increased the amount of nutrients available to plants and therefore increased growth. However, beetles did not increase plant growth in all quantitative trials, as individual effect sizes ranged from – 72 per cent to 806 per cent, suggesting important context-dependence in the provision of ecosystem services.

These findings not only highlight the ecological significance of dung beetles, but also underscore the importance of incorporating natural capital into resource and land-use decisions. By recognising the invaluable contributions of organisms like dung beetles, policymakers can better steward our ecosystems for future generations.

This research is supported by UWA and MLA Funding from the Australian Government, Department Agriculture, Fisheries and Forestry, and Rural Research and Development for Profit Program supports the Dung Beetle Ecosystem Engineers Project.

Twinning in cattle: A pathway for reducing the methane intensity of beef

Project team: Dr Joseph Gebbels[1,2] (project leader; joe.gebbels@research.uwa.edu.au), Professor Marit Kragt[1], Professor Philip Vercoe[1]

Collaborating organisation: [1]UWA; [2]Meat & Livestock Australia

Brahman cow in the field with her two calves.

Reducing livestock emissions, the largest single contributor to agricultural emissions, is increasingly recognised as a high priority. The low biological efficiency of beef cattle, due to their long gestation period, long generational interval, and propensity to be uniparous, contributes to the high methane emissions intensity (kg CO_2-e/kg product) of beef compared to most other food products.

In this project, we evaluated the potential of increasing the frequency of multiparous births (twinning) as a pathway to reducing the methane intensity of beef and the net methane emissions of intensive beef systems. We simulated a uniparous herd structure and emissions profile using GrassGro™ livestock systems modelling software and then calculate the effects of an increasing frequency of multiparous births (twinning), up to 1.53 calves per cow joined, on methane emissions.

Our results demonstrate that beef from calves reared as twins has a 22 per cent lower methane intensity than beef from a single reared calf. Although twinning reduces the methane intensity of beef, at the herd level, net methane emissions could rise by as much as 23 per cent at 1.53 calves per cow joined if overall herd size is allowed to grow through an increased number of calves. If we decrease stocking rates, whilst also increasing twinning rates, it is possible to reduce net emissions by up to 14 per cent, without changing productivity.

The results illustrate the significant potential of twinning to decrease the methane intensity of beef and to increase the productivity per cow in intensive beef systems. Despite this, twinning is unlikely to be a viable net emissions reduction pathway – as twinning will increase stocking rate unless herd structure is altered – unless a commercial or policy driver to reduce net methane emissions is established.

This research is supported by UWA.

Beeflinks R&D Program

Project team: Professor Philip Vercoe[1] (project leader; philip.vercoe@uwa.edu.au), Dr Julian Hill[2], Dr Zoey Durmic[1], Dr Joy Vadhanabuti[1], Dr Peter Hutton[1], Dr Steph Payne[1], Dr Suyog Subedi[1], Dr Lindsey Perry[4], Dr David Beatty[4]

Collaborating organisations: [1]UWA; [2]Ternes Agriculture; [3]Meat & Livestock Australia (MLA); [4]DPIRD; West Midlands Group; Gascoyne Catchment Group; Kimberley Pilbara Cattleman's Association; Mingenew Irwin Group; Select Carbon; Rio Tinto

Since it was launched in 2019, BeefLinks has focused a tight lens on beef production in the State's north – an industry challenged by the vastness of the land separating its 4000-plus cattle businesses. BeefLinks is a collaborative research and development project between UWA, MLA, and the MLA Donor Company, that aims to drive an integrated and complementary R&D program for northern and southern production systems across WA to achieve profitable, consistent and sustainable beef yields matched to consumer expectations.

The project brings together producers, researchers, businesses and state agencies to develop a greater understanding of opportunities to enhance productivity and value along the red meat supply chain. Through the program, partners will explore and understand critical control points to produce evidence-based best practices and strategies for the management and movement of cattle.

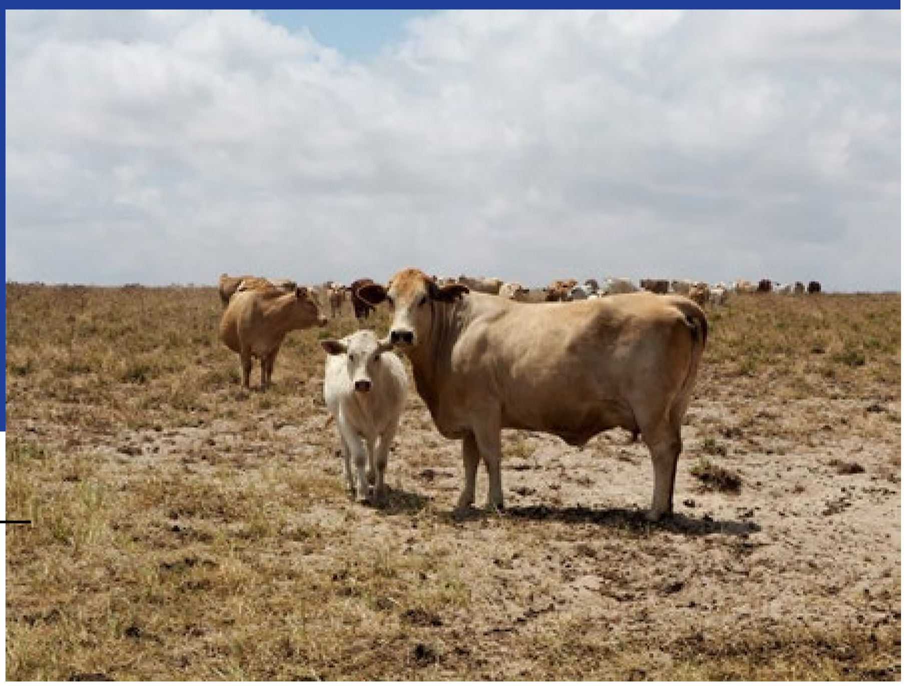
BeefLinks includes a suite of research projects covering all aspects of the industry's supply chain, including:

- Practices to improve the transition of animals from pastoral zones into backgrounding systems,
- The tracking of animal movements and diet to better inform grazing management practices that increase productivity and carbon in the landscape,
- Proof-of-principle trials of virtual fencing technology,
- Analysis of the nutritional value and methane-reducing potential of WA rangeland plants, and
- Underpinning all of these was a comprehensive socioeconomic research project that produced an economic framework for improved decision-making among producers.

The four-year BeefLinks research partnership will wrap-up in 2024. The final reporting is currently underway and will be posted on the MLA website.

This research is supported by UWA and MLA.

Professor Philip Vercoe presenting at a BeefLinks Field Day. Credit: Bob Garnant



Cattle in the Pilbara region of WA. Credit: West Midlands Group

Dr Fiona Dempster presenting at the BeefUp Forum at Roy Hill Station

Producer insights for adoption outcomes across WA BeefLinks

Project team: Dr Fiona Dempster[1] (project leader; fiona.dempster@uwa.edu.au), Professor Philip Vercoe[1], Associate Professor Fay Rola-Rubzen[1], Dr Asjad Sheikh[1], Associate Professor Michael Burton[1], Associate Professor Amin Mugera[1], Dr Curtis Rollins[1], Tammie Harold[1]

Collaborating organisations: [1]UWA; MLA

This BeefLinks project takes a transdisciplinary approach to identify strategies that maintain profitable, consistent and sustainable beef yields for the WA value chain by identifying market-based risks and strategies that can be implemented by producers and industry to minimise these risks.

In 2023, the researchers continued to conduct interviews, focus group discussions and surveys with producers and other stakeholders to gain a better understanding of the complex issues associated with:

- Decision making,
- Drivers impacting adoption rates and practice change, and
- Factors affecting producers' choice of markets.

The project will use these valuable insights to develop an economic framework for improved decision making that will ultimately build on producers' knowledge, skills, and confidence to drive practice change.

Through continuous evaluation of the BeefLinks program, the project will also recommend practical ways to improve on extension activities and adoption outcomes.

This research is supported by UWA and MLA.

Cattle eating from a food bunker, joined by many flies. Credit: Montana Baddeley

Understanding feedlot performance and eating quality of beef cattle sourced from rangelands through the WA supply chain

Project team: Dr Fiona Dempster[1] (project leader; fiona.dempster@uwa.edu.au), Professor Philip Vercoe[1], Montana Baddeley[1], Dr Asjad Sheikh[1], Tammie Harold[1], Dr Clare Engelke, Dr German Puga[1]

Collaborating organisations: [1]UWA; MLA

UWA researcher Montana Baddeley pictured with a bull.

This BeefLinks project aims to drive improvement in the on-station management of rangeland cattle by understanding how cattle perform in the WA supply chain. Changes to on-station management may also diversify market options for rangeland cattle producers.

The project is underpinned by a reference group of cattle producers and industry that will provide data and insights. Integrating other datasets collected under the BeefLinks program is a key part of the project. Cattle buyers may benefit from access to higher performing cattle from alternative cattle suppliers.

Beef producers, backgrounders, feedlot operators, processors and cattle buyers were interviewed to better understand the:

- Cattle performance required for feedlots,
- Current cattle husbandry practices used on-station and across the supply chain, and
- Meat quality of cattle from the rangelands.

An economic assessment will be conducted to evaluate the changes to on-station management, for example breeding and nutrition, that are necessary to achieve various market specifications.

The outcomes of this project include:

- Identification of the rangeland cattle best suited for the southern finishing system,
- Development of a performance data feedback loop to help inform changes to bull purchasing strategies and nutritional management programs,
- A set of recommendations and best practice guidelines produced to inform on-station practice changes that can increase access to domestic markets as well as alternative export markets, and
- Capacity building and support for the WA beef industry to identify and implement activities to optimise cattle performance.

During 2023, the project team built connections with several industry stakeholders, organising several visits to stations, backgrounding properties and feedlots for 2024. These visits aim to improve understanding of the management systems used in WA, as well as the challenges and opportunities for data collection and feedback throughout the supply chain. Additionally, the team will conduct workshops to share project findings as well as bringing in experts to share knowledge on the breeding and management interests identified by the stakeholder group.

This research is supported by UWA and MLA.

A beautiful day to install geophysics equipment at the Avon Critical Zone Observatory at UWA Farm Ridgefield. Credit: Professor Sally Thompson

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Water for Food Production

The Water for Food Production theme focuses on improved efficiencies in irrigated agriculture and better use of finite water resources to meet the food needs of an increasing world population. Thirty-seven per cent of the world's total land area is available for agricultural production, approximately 20 per cent of which is irrigated. Irrigated agriculture provides forty per cent of the world's food and can increase crop yield by two to four times when compared to rain-fed agriculture.

Western Australia is investing in horticulture development and building capacity in providing irrigated agriculture for local and international markets. The development of such irrigation schemes requires fit-for-purpose delivery systems that are economically and technically efficient, optimise on-farm water use for maximum return, and minimise detrimental impacts on the local environment.

In particular, minimisation of detrimental effects needs to focus on management of irrigation return water to the environment so as to minimise downstream water-quality issues and subsequent risks to public health. The rapid emergence of readily available sensing technology has created new opportunities for informing water-management decision-making, allowing us to identify sustainable solutions.

In dryland agriculture, yield improvements can be achieved though water conservation, requiring an understanding of how direct evaporative losses and deep drainage losses below the rootzone can be minimised.

The Water for Food Production theme undertakes research to understand where water goes after it rains, how much is available to plants and how current water losses can be reduced. This forms part of more widespread research on water balances and irrigation modelling, and environmental sensing and assessment, with a strong focus on industry collaboration and engagement, postgraduate training and technology exchange.

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The Avon Critical Zone Observatory

Project team: Associate Professor Sally Thompson[1] (project leader; sally.thompson@uwa.edu.au), Dr Konrad Miotlinksi[1], Associate Professor Matthias Leopold[1], Professor Jason Beringer[1], Allan Williams[1], Andrew van der Ven[1]

Collaborating organisations: [1]UWA; University of Adelaide; University of NSW; University of Sunshine Coast; James Cook University

We continue to develop the Avon Critical Zone Observatory in 2023. The Avon Critical Zone Observatory is one of five sites in Australia's first Critical Zone Observatory Network. Here we are learning how water, carbon and energy move through the atmosphere, plants and soils, before reaching the groundwater or bedrock. As a node in the Australian network, we can also use this site to compare these processes between different geologies and climates.

The Critical Zone is often called Earth's Living Skin. It's a little slice – maybe 200m tall - from the bedrock to the top of tree canopies. And in that little slice you find all land-based life. In the past, researchers treated the Critical Zone like a layer cake – atmospheric scientists looked at one layer, biologists, soil scientists, hydrogeologists and geologists looked at their own, different layers. But these layers affect each other. This is why Critical Zone science rotates the layer cake approach and instead looks at how all the layers work together.

This lets us get at questions like: 'Where does the carbon that our plants take in from the air go?' and 'What is it about the shape of the land and soil that can predict risk of waterlogging, and how can we manage it?' We can do experiments and change management here, revealing how different agricultural approaches might influence the big picture about water, carbon, chemicals and energy.

This year we have been analysing the data coming in from our Vadose Zone Monitoring System, and also installing more instrumentation. A big step forward has been the installation of soil moisture sensors and a piece of geophysics equipment – an Electrical Resistance Tomography (ERT) monitoring system.

Collaborations with other institutions to understand the geological history of the site and its water flow will be undertaken in 2024.

This research is supported by UWA and the ARC through the Linkage Infrastructure, Equipment and Facilities (LIEF) program.

Control of the geophysical instruments is managed from an external box, which is located outside the cropped field, allowing researchers to make measurements without disturbing the crops.

The geophysics equipment is installed into this trench to help monitor soil water content behaviour in two dimensions.

Combining electrical resistivity tomography and passive seismic to characterise the subsurface architecture of a deeply weathered hill within the Avon River Critical Zone Observatory

Project team: Jessie Weller[1] (project leader; jessie.weller@research.uwa.edu.au), Sara Jakica[2], Associate Professor Sally Thompson[1], Associate Professor Matthias Leopold[1]

Collaborating organisations: [1]UWA; [2]The Geological Survey of Western Australia, DPIRD; Terrestrial Ecosystem Research Network (TERN); AuScope

Observing the subsurface architecture of the deep Critical Zone (CZ), which lies beyond the uppermost layer of accessible soil, is a complex but crucial task. Near-surface geophysics offers an alternative to accessing the deep CZ at scales relevant for fluid, nutrient and gas transport. As geophysical instruments are sensitive to different subsurface physical properties, their combination can enhance insight into CZ architecture. However, the agreement between and complementarity of multiple geophysical techniques has not been widely assessed for CZ related questions.

We employed geophysics to image a highly weathered lateritic hill rich in iron oxides developed from Archean granite within the Avon River Critical Zone Observatory (AR-CZO), Western Australia. The AR-CZO is among five sites in the national Australian Research Council-funded Critical Zone Observation (OzCZO) network. The OzCZO network is also supported by TERN and AuScope.

The data gathered from an electrical resistivity tomography (ERT) and horizontal-to-vertical-spectral-ratio (HVSR) passive seismic transect were used to visualise CZ architecture through specific resistivity values and ambient noise contrasts. Both techniques revealed a notable degree of lateral variability consistent with erosion that led to the formation of the ~4 m duricrust capped hills, the creation of gullies in the sodic soils of the pallid zone along the slope, and the deposition of ~11 m thick colluvial sediment at the foot slope. Bedrock depth was consistent between the HVSR and ERT instruments along the hilltop but varied from about 22m to 31m on the slope and 32m to 39m at the foot slope, respectively.

PhD candidate Jessie Weller, Diego da Silva Turollo and Associate Professor Matthias Leopold running the electrical resistivity tomography device. The multielectrode system images electrical resistivity contrasts within the subsurface which are influenced by soil physical structure, mineralogy, water content and salinity of groundwater.

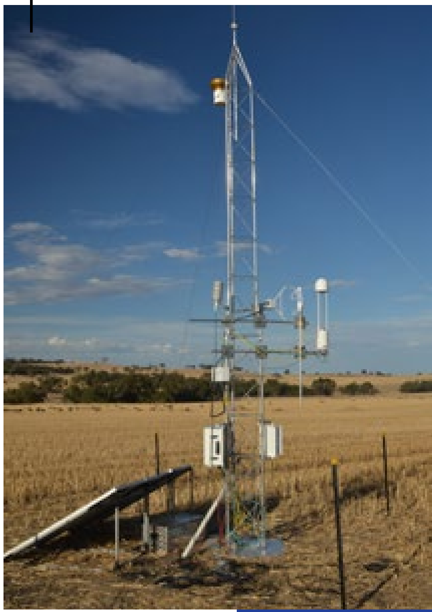
Overall, the vertical variation depicted by the ERT, including the differentiation of two layers within the lateritic weathering profile - the pallid zone and saprolite – made up for the inaccuracy of the passive seismic device in depicting layers of similar composition. Moreover, the passive seismic clearly depicted bedrock depth, combatting the partial masking of the bedrock by saline groundwater in the ERT model. The complementarity of these two methods allowed the development of a detailed model of subsurface CZ architecture within a saline lateritic weathering profile.

This research is supported by UWA, and a LIEF grant financed by the ARC.

Twenty-five passive seismic stations were set up across Averys Hill of the UWA farm covering 480m. The Tromino passive seismic device measures ambient noise induced by anthropogenic or natural forces within the subsurface.

White Conference attendees at Forrest Hall.

Avon River CZO at UWA Farm Ridgefield.



White Research Conference – Crafting a research agenda for Australian Critical Zone Science

Project team: Associate Professor Sally Thompson[1] (project leader; sally.thompson@uwa.edu.au), Dr Talitha Santini[1], Liena Fordham[1]

Collaborating organisation: [1]UWA

The White Research Conference, held in Perth from 21 to 23 November 2023, established the Critical Zone (CZ) – the vertical span from the atmospheric boundary layer to the bedrock within which almost all terrestrial life is found – as a subject of transdisciplinary study, and Australia's new Critical Zone Observatories as a meeting place for minds.

The conference brought together a diverse group of scientists from undergraduate students to leaders of national research networks to exchange knowledge about the CZ and identify the scientific priorities for researchers in this discipline. Historically siloed communities were brought together for productive conversation, and there was palpable excitement as regolith scientists considered how their knowledge set the stage for contemporary studies of the structure and function of the CZ, while geomorphologists, ecologists and hydrologists explored how processes from deep time and past climates have left legacies shaping the contemporary landscape.

Conference participants were challenged by former Western Australian Chief Scientist Lyn Beazley to consider the "four legs of the stool" for CZ Science – the importance of partnership between community, academe, industry and Government to build a lasting scientific enterprise. International speaker Professor Bill Dietrich shared lessons from the United States' Critical Zone Observatory projects and identified a rich suite of questions that Australian CZ Science can answer for the global community. Professor and Nyungar elder Len Collard challenged scientists speaking the language of science to also learn to speak local indigenous languages and engage with stories about the soil, water and land as CZ Science progresses, before Dr. Simone Gelsinari demonstrated the value of a CZ approach to gain insights into fundamental questions about water supplies as climate changes.

Thoughts provoked by these keynote addresses, the conference moved to the Boola Bardip Western Australian Museum, where early career participants shared posters of their research, and conference goers became familiar with each other's expertise and interests during the poster session and subsequent tour of the 'Origins' Gallery – an experience which echoed the already emerging themes of our ancient landscape, deep indigenous wisdom and understanding of the land, and how the interplay of biology, chemistry and geology in the CZ created contemporary landscapes, minerals and ecosystems.

Workshops on the second day of the conference split participants into small groups based on self-selection of topics of interest, and participants attempted to synthesize existing knowledge, relevance, and important knowledge gaps around topics such as 'Water in the CZ', 'Carbon in the CZ', 'Evolution of the CZ' and 'Mineral resources in the CZ', before proposing research actions needed by scientists to address these topics. Scientific priorities identified included using a CZ approach to understand how water availability for people and ecosystems will change in response to the changing climate; assisting in the quantification of deep (below 1m in the soil) carbon storage and cycling processes; improved bioprospecting strategies; and a broad suite of calibration and validation activities for tools ranging from remote sensing, to models, to carbon accounting calculators. As such, the CZ Science Agenda aligns closely with all the draft national science priorities, and perhaps most especially to: 'Ensuring a net zero future and protecting Australia's biodiversity', and 'Enabling a productive and innovative economy'.

Strategic challenges facing the CZ community in Australia were also identified and discussed, and include the lack of ongoing operational funding for the newly established CZ Observatories, the lack of a dedicated Critical Zone Science journal and the lack of dedicated CZ conferences. CZ Science is exciting because it lies at the interface of many disciplines – but this transdisciplinary comes with the need to align calendars, publishing opportunities, and creating opportunities for disciplines to engage with each other. With that in mind, the participants were unanimous in their desire for ongoing follow-up workshops to allow these communities to engage with each other as Australian CZ Science continues to develop.

This research is supported by UWA through the Forrest Foundation, schools of Engineering, Agriculture and Environment and The Institute of Agriculture.

Conference participants at Boola Bardip WA Museum.

Can biodrainage help mitigate erosion in the Ethiopian Highlands – A modeling study

Project team: Associate Professor Sally Thompson[1] (project leader; sally.thompson@uwa.edu.au), Dr Liya Weldegebriel[2], Dr Seifu Tilahun[3,4], Associate Professor Christian Guzma[5]

Collaborating organisation: [1]UWA; [2]Stanford University, US; [3]Bahir Dar Institute of Technology, Ethiopia; [4]Texas A&M University, USA; [5]University of Massachusetts, USA

Reversal of land degradation in agricultural systems through a wide range of natural resources management tailored to the specific climate, soil, and topography is crucial. This is especially critical for subsistence farming systems such as the Ethiopian Highlands, subject to some of the highest soil erosion rates in the world. Although biodrainage – the planting of vegetation strategically to dewater soil – is widely and successfully used for waterlogging and erosion control in arid regions, it is not widely applied in sub-humid places like the Ethiopian Highlands.

Beginning with field observations of the complex vertical soil profiles and variations in lithology and soil hydraulic properties along a hillslope ridge-channel transect in the Debre Mawi watershed of the Abay (Upper Blue Nile) Basin in the Ethiopian Highlands, we constructed a synthetic model hillslope using the unsaturated flow simulation software, HYRDUS-2D.

The growing season in the Ethiopian Highlands coincides with the rainy season, a period known as Kiremt. We calibrated hillslope water storage using observations of water table elevation.

The synthetic hillslope was then used to test the feasibility of biodrainage to mitigate saturation, which is a major driver of gullying and soil loss in the Ethiopian Highlands, and to identify plant traits to which such mitigation is sensitive.

Eucalyptus planting and maize fields in Shanko Bahir subwatershed in the Ethiopian Highlands. Credit: Liya Weldegebriel

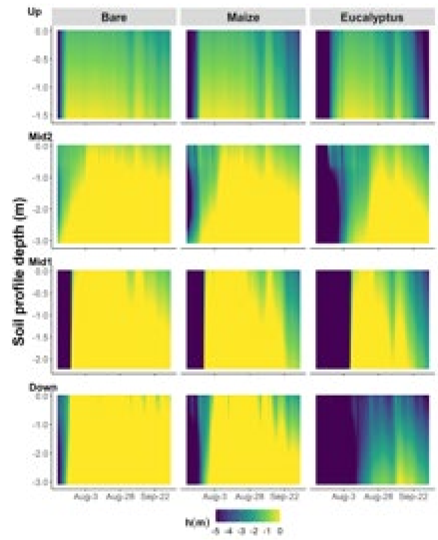
The simulation results using bare soil, eucalyptus and maize land covers revealed that in spite of low potential evapotranspiration during the Kiremt season, biodrainage with eucalyptus can reduce the occurrence and duration of saturation of the top 0.6m surface soil profile of the hillslope.

Of the different plant traits explored, the maximum soil water potential at which the crop can transpire at potential rates, and the leaf area index (LAI), which controls potential evaporation rates via the crop coefficient, provide the most important controls on the effectiveness of biodrainage in desaturating the hillslope.

Biodrainage strategies to mitigate soil erosion in sub humid locales merit further investigation through empirical trials. However, implementation of biodrainage strategies should be subject to thoughtful consideration of the implications for socio-economic outcomes and the local environment.

The work has recently been accepted for publication in the journal *Catena*.

This research is supported by the NSF Graduate Research Fellowships Program (GRFP) under Grant No. DGE 1752814 and 580 DGE-1633740.



Model results illustrating the progression of soil moisture conditions over time (from left to right) and depth in the soil (from top to bottom) for different locations on the hillslope and biodrainage plant species. Blue colours represent dry soils, and yellow represents conditions approaching saturation. Eucalyptus is effective at maintaining drier soil conditions in most locations along the synthetic hillslope.

Deep soil water use of old-aged vegetation (17 to 36-year stand age) after the formation of dried soil layers based on *in situ* monitoring

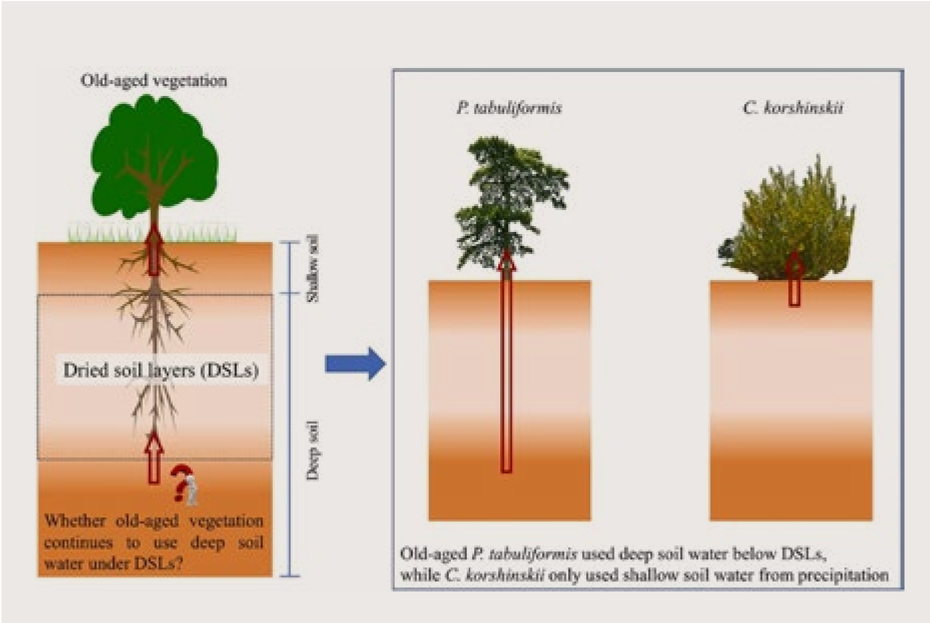
Project team: Professor Min Li[2] (project leader; limin2016@nwafu.edu.cn), Dr Guangjie Chen[2], Dr Qifan Wu[3], Dr Yanbo Wang[2], Dr Yihong Zhao[2], Dr Haiyang Yu[2], Yunqing Lu[4], Dr Hao Feng[2], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]North China University of Water Resources and Electric Power, China; [4]Shanghai Investigation Design & Research Institute Co Ltd, China

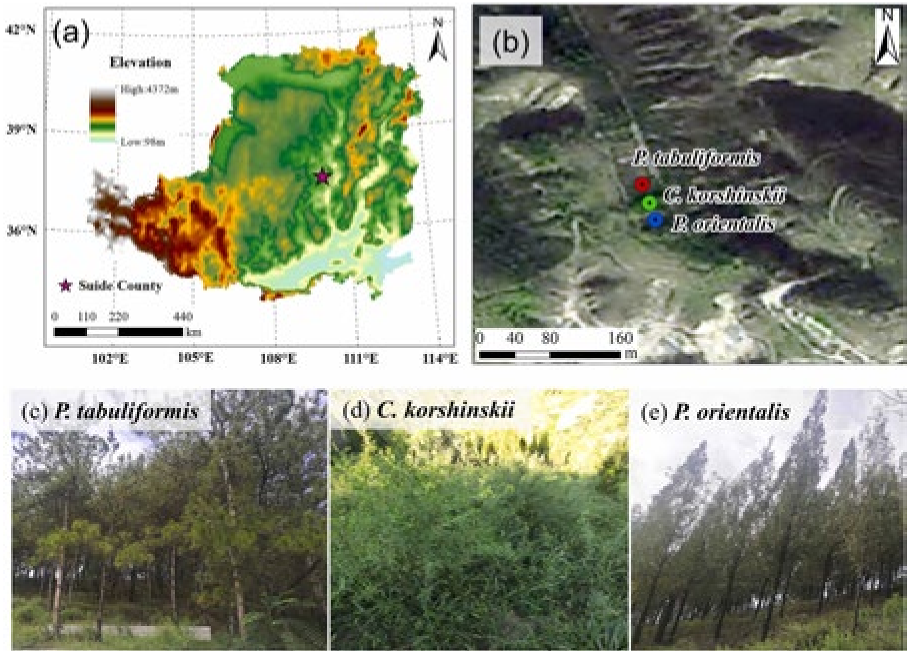
To analyse whether old-aged vegetation use deep soil water (DSW) in the setting of the dried soil layers (DSLs), the research team studied five soil water data for nearly 20 years (17 to 36-year stand age) from in situ soil water monitoring of old-aged vegetation. They emphasise the use potential of deep soil water in the presence of DSLs. The results showed that P. *tabuliformis* used deep water (17–22m soil layer) from 23 to 36 years (average 11.6mm y−1), while old-aged C. *korshinskii* did not uptake deep water. They also found that the three vegetation types did not use DSW within the DSLs based on historical soil water and soil water storage changes. Furthermore, DSW content was related to clay content rather than vegetation type under long-term deficit.

This work deepens the researchers' concerns about the imbalance of water resources caused by excessive consumption of DSW in semi-arid areas of the Loess Plateau. On the one hand, DSW use for various revegetation species in long-term ecological restoration should be considered. On the other hand, this study will provide foundational information for optimal water resources management scheme from the perspective of long-term deep-soil drought.

This research is supported by the National Key R&D Program of China, Key Science and Technology Program of Henan Province, China, National Natural Science Foundation of China, and the 111 Project.



The graphical abstract of the study.



Study area on the Loess Plateau in China and locations of three vegetation types in the Xindiangou Watershed.

APRH Journal 'Water Resources'

Project team: Adjunct Professor Susana Neto[1,2] (project leader; susana.neto@netcabo.pt)

Collaborating organisations: [1]UWA; [2]University of Lisbon, Portugal

The journal was created in 1980 and, as a periodical, filled an important gap in the scientific and technical universe in water resources in Portuguese, becoming an important means of disseminating articles in this area. In 2010 the online version was made available and in 2016 the journal acquired a new profile, aiming to strengthen its role as a privileged vehicle for presenting opinions, launching debate and bringing together suggestions for proposals on various critical issues at national level, while also echoing the major issues on the international agenda. The objectives include this magazine to be a priority medium for the administration to set out its vision of possible legislative and institutional changes, for the dissemination of the internal reflections of APRH, its members and the technical-scientific community, and also for the presentation of commented summaries of the conclusions of the events organized by the Association. Articles are carefully evaluated by accredited and independent reviewers. The articles (as well as the entire journal) are available online, so they have a target audience of millions of readers and a high chance of being cited, making it possible to increase impact rates. The articles published in this journal are identified with a DOI (Digital Object Identifier).

Since UWA Adjunct Professor Susana Neto was appointed as Director of the editorial board, four issues have been published. In 2023, two Special Issues were published, the first dedicated to the APRH Biannual Congress, and the second dedicated to the celebration of the 25 years passed over the signature of the important international agreement between Portugal and Spain: The Albufeira Convention - (Convention on Cooperation for the Protection and Sustainable Use of the Waters of the Luso-Spanish River Basins) – which is one of the best European examples of application of the concepts advocated by the United Nations and UNECE in the New York, and Helsinki Conventions.

This research is supported by the Associação Portuguesa de Recursos Hídricos (APRH).

Director of the editorial board UWA Adjunct Professor Susana Neto.

The December 2023 front cover of the APRH Journal '*Water Resources.*

Elevating river basin governance and cooperation in the Hindu Kush Himalaya region

Project team: Will Fargher[2] (project leader; will.fargher@ricardo.com), Dr Hemant Ojha[3], Adjunct Professor Jeff Camkin[1,3], Dr Basundhara Bhattarai[3], Priyanka Gurung[3], Noah Kaiser[2], Huw Pohlner[2], Cassandra Stevenson[2], Luke Dowdeswell-Downey[2], Russell Rollason[4], Trudy Green[4]

Collaborating organisations: [1]UWA; [2]Aither Pty Ltd, Australia; [3]Institute for Study and Development Worldwide, NSW; [4]eWater, ACT; International Centre for Integrated Mountain Development; Australian Water Partnership

The Australian Water Partnership (AWP) and the International Centre for Integrated Mountain Development (ICIMOD) signed an MoU in 2019 aimed at strengthening bilateral water cooperation between Australia and countries of the Hindu Kush Himalayan (HKH) region of Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan.

From 2021-2023, the MoU supported an analysis of the challenges and opportunities for basin-wide management in three focus basins: the Indus, the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna ('Brahmaputra'), and the Ganges. Undertaken by an Aither-Institute for Study and Development Worldwide-eWater consortium, this included analyses of issues such as gender equity, disability, and social inclusion, upstream-downstream governance arrangements, data and knowledge availability and sharing, and climate change resilience and adaptation. The study resulted in high-level recommendations for strengthening basin-wide cooperation. The recommendations were then tested further and advanced through Knowledge Exchange and Dialogue sessions with stakeholders for each focus basin. Individual summary reports document the context, challenges, and opportunities for managing the basin water resources.

High-level recommendations for the Brahmaputra basin, for example, included:

1) Use common goals and mutual gains as catalysts for bilateral, trilateral, and multilateral cooperation,
2) Focus on building trust and increasing awareness of the economic, political, social, and environmental benefits of transboundary cooperation,
3) Use existing bilateral cooperation as a platform for expansion,
4) Support and catalyse collaborative basin-wide assessments,
5) Strengthen gender and social inclusion in knowledge generation, dialogues, planning, and cooperation from the local to basin scales,
6) Strengthen the capacity of the water and development sectors in South Asia, and
7) Connect river basin governance to multilateral trade and investment fora.

Three summary reports on elevating river basin governance and cooperation in the HKH region, focusing respectively on the Brahmaputra, Ganges, and Indus River basins are available at https://www.icimod.org/river-basins-reports/. The reports are now supporting the ICIMOD by informing further dialogue on river basin governance in the HKH region.

This research is supported by the Australian Government through the Department of Foreign Affairs and Trade.

Elevating river basin governance and cooperation in the HKH region: Summary Report I, Yarlung-Tsangpo-Siang-Brahmaputra-Jamuna River Basin

Summary Report II, Ganges River Basin.

UPWATER - Understanding groundwater Pollution to protect and enhance WATERquality

UWA project team: Adjunct Professor Jeff Camkin[1] (project leader; jeff.camkin@uwa.edu.au), Adjunct Professor Susana Neto[1]

Collaborating organisations: [1]UWA; Agencia Estatal Consejo superior de Investigaciones Científicas, Spain (UPWATER leader); Aarhus University, Denmark; Institut National de L'Environnement Industriel et des Risques, France; IWW Rheinisch-Westfälisches Institut für Wasserforschung gemeinnützige GmbH, Germany; National Technical University of Athens, Greece; Universitat de Barcelona, Spain; Stichting Future City, Netherlands; Fundación Nueva Cultura del Agua, Spain; TARH-Terra, Ambiente e Recursos Hidricos Lda, Portugal; Barcelona Regional Agencia Metropolitana de Desenvolupament Urbanístic d'infrastructures SA, Spain; Athens Water Supply and Sewerage Company, Greece

A group of UPWATER researchers begun the sampling campaign for the Besòs aquiferin Spain in late 2023.

UWA continues to play an important role in the EU-funded project UPWATER (Understanding groundwater Pollution to protect and enhance WATERquality). As an affiliated organisation, UWA, along with the Australian Nuclear Science and Technology Organisation (ANSTO) and 13 European project partners are developing tools and strategies to implement safe and contaminant-free recharge water into aquifers.

Through case study sites in Stengaarden (Denmark), Besós (Spain) and Athens (Greece), UPWATER is helping to increase public awareness of the advantages of engineered natural treatment systems to enhance water quality while providing evidence, models, and methods applicable through regulatory and governance decisions.

Technological and analytical strategies are being used in each case study to:

i) Monitor groundwater pollutants,
ii) Evaluate the efficiency of bio-based solutions for pollution mitigation, and
iii) Develop and update groundwater models for each site.

Stakeholder participatory processes and multi-criteria analysis in each site are identify the best pollution prevention policy options for each context, based on the specific social, environmental and economic characteristics of the area. Policy briefs will then be prepared to inform policymakers.

The UWA Institute of Agriculture Adjunct Professor Jeff Camkin, who has considerable experience in the governance of water and other natural resources in Australia and elsewhere, has responsibility within UPWATER for linkage policy to practice through the development of the UPWATER policy briefs for policymakers at the local/regional and European Union levels.

UWA contributions to date include facilitating the deployment and trial of new passive samplers to measure groundwater pollutants in Sydney and Perth, facilitating the involvement of Australian groundwater experts in a series of focus group workshops as part of EU Green Week, and guiding project activities on the information required to inform effective policy briefs.

Western Australia is highly dependent on groundwater and has consequently developed strong groundwater management skills with lots of learning along the way. The involvement of Western Australian expertise in groundwater protection, water law and governance from UWA, government and private enterprise in UPWATER activities provides a tremendous opportunity to share experiences in managing this critical resource.

This research is supported by the European Union under grant agreement 101081807 Project UPWATER.

The first annual UPWATER General Meeting was held in Athens from 8-10 November. Among the field trips was visiting the wastewater treatment facility at Psytthaleia Island.

The Great Renaissance Dam in Ethiopia.

Coping with water scarcity: New advances in Africa and beyond

Project team: Adjunct Professor Susana Neto[1,2] (project leader; susana.neto@netcabo.pt), Adjunct Professor Jeff Camkin[1,2], Professor Ragab Ragab[3], Dr Nadine Depre, Dr EL Houssine Bartali[4], Dr Mohamed Wahba[5], Dr Elhassnaoui Ismail[6]

Collaborating organisations: [1]UWA; [2]University of Lisbon, Portugal; [3]UK Centre for Hydrology; [4]IAV Hassan II Rabat, Morocco; [5]Al Agamy Al Bahri, Egypt; [6]Mohammadia School of Engineers, Morrocco; Moroccan National Committee of the International Commission on Irrigation and Drainage

Water availability per person has generally been decreasing around the world as populations grow, with greatest declines in countries with the lowest per capita internal renewable water resources (IRWRs), which are often located in Sub-Saharan Africa (41 per cent), Central Asia (30 per cent), Western Asia (29 per cent), and Northern Africa (26 per cent) (FAO, 2022). The global urban population facing water scarcity is projected to increase from 933 million (one-third of global urban population) in 2016 to 1.7–2.4 billion people (one-third to nearly half of global urban population) in 2050 (He et al., 2021). Considering this new reality, the World Water Policy Journal launched a Special Issue in 2023, led by editors-in-chief adjunct professors Susana Neto and Jeff Camkin, acknowledging the need to address current water and climate challenges and prepare for future challenges, with new, innovative ways to address those challenges.

With agriculture using about 72 per cent of the global freshwater withdrawals (UN, 2023) and a continuation of rapid urban growth expected to result in an 80 per cent increase in urban water demand by 2050 (Flörke et al., 2018), the reallocation of water from agriculture to urban centres is becoming a common strategy to address competition for freshwater in some regions. The increasing competition for water and pressure for reallocation of water to urban centres have driven interest in improving irrigation water use, including the adoption of water-saving irrigation technologies and approaches, and investment in the development of new irrigation technology, among other policy measures. One area of interest is micro-irrigation—the application of water at low volume, low pressure, and high frequency aimed directly at the root zone of plants—which can reduce the likelihood of overwatering and prevent runoff and evaporation. Through surface or sub-surface application, micro-irrigation can increase yields and decrease water, fertiliser, and labour requirements. Irrigation technologies alone are not a solution, however. New technologies must be matched by an understanding of the specific irrigation context and local and national needs, proper design, operation, and maintenance of irrigation systems, and a supportive water governance framework that understands the benefits of new technology and encourages its use where appropriate.

For all these important reasons, World Water Policy Journal Issue 9.4 was a special issue dedicated to water policy and practice in Africa. Part 1 was a set of papers that built upon presentations at the 10th Micro-irrigation Conference, which was organised by the Moroccan National Committee of the International Commission on Irrigation and Drainage (ANAFIDE), from 25 to 27 January 2023 at Dakhla in Southern Morocco. In their Guest Editorial *'Micro irrigation in the era of technology: innovation and digital transformation'*, Professor Ragab Ragab and Dr Nadine Depre describe the history and context for increased focus on micro-irrigation before introducing the 13 papers in this Part, many of which were prepared by emerging water professionals. Topics are wide-ranging, including state-of-the-art technologies, improving micro-irrigation in practice, and supportive water and agricultural policy and planning frameworks in Africa and beyond.

A further six papers about broader aspects of water policy and practice in Africa were presented in Part 2. In the first paper, Ismail Elhassnaoui and co-authors discuss the past, present, and future of the Africa Green Revolution, focusing on Kenya, Morocco, and Nigeria. Dooa Salman and co-authors then describe the water stress and sustainability challenges in Sub-Saharan Africa. The adoption of rainwater harvesting as a sustainable approach to improving the climate resilience of small landholders in Kenya is the focus of a paper by Neil Coles and Kristin Mutschinski. Don Chiumya and Jabulan then present the findings of their investigation into the impact of prepaid meters on communal water points in the peri-urban areas of Lilongwe, Malawi. The willingness of rural households to pay for irrigation water use in the North Shewa Zone of Ethiopia is discussed by Yitea Seneshaw Getahun. In the final paper in this issue, Jongeun You discusses the policy conflicts around the Great Ethiopian Renaissance Dam.

This research (World Water Policy Journal) is supported by the Policy Studies Organization and published by Wiley.

Speakers at the 10th Micro-irrigation Conference in Morrocco

Malaysia-UNESCO Cooperation Program – Progressing together: MUCP contributions to a sustainable future

Project team: Adjunct Professor Jeff Camkin[1,2] (project leader; jeff.camkin@uwa.edu.au), Icyimpaye Adeline, Ifeanyi Emmanuel Anyanwu, Saber Sayed Sharifi

Collaborating organisations: [1]UWA; [2]Institute for Study and Development Worldwide (IFSD), NSW; UNESCO Jakarta Office; Malaysian Government

From 22 to 24 June 2023, participants from Asia, the Pacific, Africa, and beyond came together in Kuala Lumpur for a very special event - Progressing Together: MUCP Contributions to a Sustainable Future to celebrate the achievements of the Malaysia-UNESCO Cooperation Programme (MUCP).

Launched in 2013 under the joint leadership of Malaysia and UNESCO with funding from the Government of Malaysia, the MUCP promoted and supported a wide range of educational, scientific, and cultural activities across Least Developed Countries (LDCs) and Small Island Developing States (SDSs) in Asia, the Pacific, and Africa, with the overall goal of fostering sustainable development, preserving cultural heritage, and advancing knowledge and innovation.

With a special emphasis on countries of the Global South working together through South-South Cooperation, MUCP served as a platform for collaboration and exchange of expertise between Malaysian institutions, UNESCO, and partner countries. Over 10 years, almost 7,000 participants from government, non-government, civil society, youth, academia, and UNESCO networks participated in MUCP, sharing ideas and building capacity to address key challenges and opportunities for a more sustainable future.

Involving participants from 87 countries across Asia and the Pacific, LDCs, SIDS, and Africa, MUCP completed 36 projects, including support for young artisans, devising appropriate water policies, practices, and education, ensuring disaster risk resilience to UNESCO-designated sites, and empowering girls and STEM (Science, Technology, Education and Mathematics) for education. In addition, the programme addressed the challenges of climate change from the perspective of journalism, promoting inclusive social development, as well as open sciences. By garnering a pool of expertise and dedication, all MUCP partners worked together on a transversal competencies approach to create transversal solutions for a sustainable future.

The successful strategic cooperation between Malaysia and UNESCO can be emulated by other countries towards global commitments to enhance social cohesion in building forward differently to accelerate the achievement of SDGs.

The official launch of the MUCP Coffee Table Book Malaysia-UNESCO Cooperation Programme: Progressing Together: MUCP Contributions to a Sustainable Future was among the highlights of the event. The book is a compilation of success stories of MUCP that recapitulate a decade of interdisciplinary activities. It serves as a reference for future generations.

This research (MUCP) was supported by the Malaysian Government and UNESCO, along with partner contributions. Adjunct Professor Camkin's activity was supported by UNESCO and IFSD.

The UWA Institute of Agriculture Adjunct Professor Jeff Camkin with panellists and participants at the MUCP session on Achievements in Culture. Credit: UNESCO

Field day for the cycle 2 trial of the rapid cooking bean project.
See page 92. Credit: ACIAR

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Food Quality and Human Health

Health attributes of foods is an important driver for food choices. Consumption of healthy foods is the cornerstone of efforts to improve diet quality in populations. Higher intake of plant foods is associated with lower risk of many chronic diseases including diabetes and cardiovascular disease.

The aim of this theme is to develop healthier foods and food ingredients that can make a positive contribution to human health and the Australian economy. The development and validation of healthy foods that meet consumer desires is an exciting challenge for the Australian agri-food industries. Critical for achieving these outcomes is the establishment of cross-disciplinary collaborations and collaboration with relevant industries. This research theme integrates the complementary skills, knowledge and activities across disciplines and organisations that will enable increased success.

The research is leading towards the development of a collection of healthy functional foods and ingredients, as well as improved processes for their production and manufacture. The research will deliver scientifically validated evidence for the promotion of new foods, as well as significant added value to agricultural industries.

Theme Leaders

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Novel agronomic practices to achieve productive and profitable viticulture in northern Australia

Project team: Associate Professor Michael Considine[1,2] (project leader; michael.considine@uwa.edu.au), Emeritus Professor John Considine[1], Aimee Grieves[2], Dr Chris Ham[2], Dr Melanie Ford[2], Dr Dario Stefanelli[2], Wenyi Xu[1], Antoni Ciampi[3], Joseph Ekman[3,4], Cristina Paez[1]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]Fruitico; [4]Fresh Produce Group

The 2016 Federal White Paper on Developing Northern Australia illustrated the shallow depth of the agriculture industry, which was overwhelmingly concentrated in cattle, followed distantly by sugar cane and then banana. The White Paper called for an intensification of agriculture, particularly with horticulture.

Table grape is Australia's most valuable horticultural crop, presently $1 billion (2024 value, Australian Bureau of Agricultural and Resource Economics and Sciences), generating $850M export value. By comparison, avocado, banana and mango production are valued at $450M, $600M and $185M, respectively. However, table grape production is concentrated in the south-east of Australia, with 78 per cent in Victoria alone, and >90 per cent production below 30 °S latitude (Australian Table Grape Growers Association, 2024). As a result, Australia imports >$80M table grapes annually to meet seasonal gaps.

Table grapes were domesticated in a Mediterranean climate, however, show wide plasticity and are commercially grown in subtropical and even tropical countries such as Brazil. There is presently some table grape production in subtropical and tropical regions of Australia, however the yield penalty compared with southern regions is four to five-fold. Nevertheless, there is considerable opportunity for import replacement, particularly if production constraints can be overcome.

Therefore, the objective of this project is to support industry to achieve a change in the agronomic management of table grapes in tropical and subtropical northern Australia that will increase yield and predictability.

The specific objectives are:

- Evaluate agronomic techniques such as pruning and irrigation to determine optimal strategies for table grape production in northern Australia,
- Develop a phytosanitary management strategy for the control of pests and diseases for cultivation of table grapes in tropical areas,
- Study the effect of the use of plant hormones on the physiology of grapevines grown in northern Australia,
- Analysis of the agronomic behaviour of different commercial varieties of table grapes in tropical and subtropical viticulture in Australia, and
- Study of the physiology of the vine and its adaptation to cultivation in non-Mediterranean climates.

During 2023, we implemented the first stage of trials on a commercial farm in Broome. These first field trials provided more challenges than expected and showed clear signs that greater consideration should be given to other technical and environmental aspects. In 2024, the team will continue to advance this research both in Broome and in controlled environment experiments in the UWA facilities.

This research is supported by the CRC for Developing Northern Australia, as part of the Australian Government's Cooperative Research Centre Program.

Collection of pruning weights and yield of table grape vines in Broome, assisted by staff of Kimberley Table Grapes.

Sweet Globe table grape bunches, ready for yield and quality assessment before packing.

How do perennial tree crops adapt to changes in seasonality? Ascorbate and glutathione integrate the control of grapevine development

Project team: Associate Professor Michael Considine[1,2] (project leader; michael.considine@uwa.edu.au), Dr Aneta Ivanova[1], Dr Paul Boss[3], Dr Christine Bottcher[3], Debra McDavid[3], Professor Christine Foyer[4], Wenyi Xu[1]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]CSIRO Adelaide; [4]University of Birmingham, UK

Tissue culture of genetically modified grapevine plants at the CSIRO Agriculture and Food Lab, Adelaide.

Antioxidants are important for plants. Deficiencies in ascorbate or glutathione – the two most important soluble antioxidants in plants – results in slow and stunted growth and susceptibility to environmental stress. This knowledge has been incredibly important for crop improvement in cereals and legumes, but is yet to be applied to woody perennials such as grapevine.

Our group investigates the control of perennial fruit crop production in different climates. Grapevine is an important crop for fresh and processed fruit industries and has become a model for understanding how perennial tree crops adapt to climate and changes in seasonality.

This project, funded by an ARC Discovery Project, in partnership with the CSIRO Plant Industries (Adelaide), seeks to translate knowledge of how key regulators of annual growth perform and function in perennial plants. The project seeks to determine how ascorbate or glutathione control development, flowering and dormancy in grapevine.

As a team, we have constructed genetically modified grapevines which are deficient in ascorbate or glutathione. The vines will be studied under contained (Physical Containment Level 2) conditions at UWA and evaluated for their development and stress response.

This is the first time functional genetics has been applied to a woody crop in WA. Importantly, our partners at CSIRO are also developing novel gene editing tools that could allow the creation of new, precisely edited clones without 'genetic modification', as it is defined in Australia. Hence this study will help to bridge the knowledge gap in identifying gene targets for gene editing, particularly for climate resilience.

This research is supported by UWA and the ARC.

Red clover growing in enclosed shadehouse.

PhD candidate Sharmin Sultana conducts monofloral clover honey collection.

Phytochemical analysis and bioactivity profiling of clover honeys

Project team: Associate Professor Cornelia Locher[1] (project leader; connie.locher@uwa.edu.au), Sharmin Sultana[1], Dr Kevin Foster[1,2], Professor Lee Yong Lim[1], Dr Katherine Hammer[1]

Collaborating organisations: [1]UWA; [2]DPIRD

This study is the first to report on a number of phytochemical (i.e. phytoestrogen, total phenolic content, sugar profile) and physicochemical characteristics (i.e. pH, colour, moisture content) and in vitro antioxidant activity (FRAP, DPPH) of monofloral clover honeys (unripe and mature). The production of monofloral clover honey was initiated with the seedlings of the following clover cultivars: two red clover (*Trifolium pratense*) cultivars (NSE and NFE), a purple clover (*T. purpureum*) cultivar, Electra and a sainfoin clover (*Onobrychis viciifolia*) cultivar, Othello. The cultivars were then moved into their designated plot inside a shade house enclosure at the UWA Shenton Park Field Station and a nucleus beehive was installed. This approach allowed to produce monofloral honeys and therefore to derive typical phytochemical characteristics for each clover honey without potential interference from co-flowering species as might be the case for wild-harvested honeys.

A special focus was given on the presence of oestrogenic compounds in different clover flower nectar samples, in bee-deposited nectars collected from hive combs (unripe honey) and in mature honeys harvested from the same hives. A total of eight isoflavones, four of them non-glycosidic (methylated form- biochanin A & formononetin and demethylated form- genistein & daidzein) and others glycosidic (sissotrin, ononin, genistin and daidzin), were targeted for identification and quantification using high-performance thin-layer chromatography (HPTLC). Leaves and flower bracts of the clover samples were also investigated. Different isoflavone profiles were found across the clover species and also in the different samples collected from each species indicating that, most likely due to the activity of honeybee (*Apis mellifera*) salivary enzymes, biochemical conversions take place when these bioactive compounds transition from flower nectar into mature honey.

Although research into the phytochemical composition of various honeys and their associated bioactivities is growing, there is little published information on clover honeys. This created the impetus for this study to investigate the chemical composition and bioactivities of different clover honeys, as well as to explore potential future opportunities for both the pharmaceutical and apiculture industries. While all clover honeys were found to be slightly more acidic and have a slightly higher water content, they exhibited similar fructose and glucose ratios compared to more than 400 Western Australian honeys that were investigated using the same methodologies in UWA's honey research lab. The clover honeys were also found to have a medium strength antioxidant activity which was measured using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) and Ferric Reducing Antioxidant Power (FRAP) assays and a moderate amount of phenolic constituents (measured as total phenolic content) when compared to other WA honeys.

This research is supported by UWA.

Determinants of organic food purchase intention: The moderating role of health consciousness

Project team: Professor Gurmeet Singh[2] (project leader; gurmeet.singh@usp.ac.fj), Kritika Devi, Professor Sanjit Roy[1], Dr Juraj Cúg[3]

Collaborating organisations: [1]UWA; [2]The University of the South Pacific, Fiji; [3]University of Žilina, Slovakia

The purpose of this study is to understand the effects of self-risk perception (a person's subjective judgments about the likelihood of negative outcomes) and health consciousness on the intention to purchase organic food. The study also explored external factors, such as social networking, culture and their impact on attitude, self-risk perception and purchasing organic food.

This study uses a quantitative research method to collect data from New Zealand and Fiji (N = 701). The data analysis used the partial least squares path modeling technique (PLS-PM) to test the proposed model. The empirical results revealed that self-risk perception positively influenced organic food intention. The results show that the health consciousness level strengthens the relationship between self-risk perception, beliefs, values and purchase intention. The health consciousness level dampens the relationship between social networking and purchase intention. The findings of this study provide valuable insights into the guidance and promotion of Fijian and New Zealand's organic food industry.

This study enables marketers to develop health-related promotional tactics to stimulate organic food sales. It gauges organic food promoters to use social media-oriented consumer networking to spread health awareness swiftly. This comprehensive study extends the literature by scrutinizing the profundity of self-risk perception and health consciousness in influencing and explaining consumers' purchase intentions. Aside from ample growth in the study of organic food purchase intention, which commonly replicates simple relationships, this study ascertains deeper meaning and new relationships to understand the moderating role of health consciousness levels in organic food studies, expanding the theory of planned behaviour.

This research is supported by the University of the South Pacific.

Dried legumes and grains for sale in an organic store. Credit: Janine Lamontagne

Hands-on training in Uganda in February 2023 was successful in transferring skills in data management and data analysis in crop breeding.

Dried common beans *Phaseolus vulgaris* L.

Rapid breeding for reduced cooking time and enhanced nutritional quality in common bean (*Phaseolus vulgaris*)

Project team: Professor Wallace Cowling[1] (project leader; wallace.cowling@uwa.edu.au), Dr Renu Saradadevi[1], Hackett Professor Kadambot Siddique[1], Dr Clare Mukankusi[2], Winnifred Amongi[2], Jean-Claude Rubyogo[3], Dr Teshale Assefa[4], Annuarite Uwera[5], Abel Moges[6], Blaise Ndabashinze[7], Julius Mbiu[8], Shamir Misango[9], Dr Stanley Nkalubo[10]

Collaborating organisations: [1]UWA; [2]Alliance-Uganda; [3]Pan-Africa Bean Research Alliance (PABRA); [4]Alliance-Tanzania; [5]Rwanda Agriculture Development Board (RADB); [6]Ethiopian Institute of Agricultural Research (EIAR); [7]Institut des Sciences Agronomiques du Burundi (ISABU); [8]Tanzania Agricultural Research Institute (TARI); [9]Kenya Agricultural and Livestock Research Organization (KALRO); [10]National Crops Resources Research Institute (NaCRRI), Uganda

This Australian Centre for International Agricultural Research-funded project is led by UWA's Professor Wallace Cowling and Research Associate Dr Renu Saradadevi. Our team includes the common bean breeding team at The Alliance of Bioversity International and CIAT in Uganda (Alliance-UGA), the Pan Africa Bean Research Alliance (PABRA), and bean breeders in six partner countries in East Africa. The Australian team was boosted by Dr Li Li and Emeritus Professor Brian Kinghorn at the University of New England. During five years of the project from 2019 to 2024, the project aims to reduce cooking time (CKT) in African common bean by at least 30 per cent and increase iron (Fe) content by 15 per cent and zinc (Zn) by 10 per cent. The project employs new breeding methods based on pedigree and genomic information together with optimal contribution selection (OCS) to accelerate genetic improvement of biofortified and rapid cooking common bean. This breeding method is abbreviated in the acronym BRIO.

Since the project began in 2019, the bean breeding team has undertaken annual rounds of crossing from which progeny plants are grown, genotyped and evaluated for CKT, Fe, Zn at Alliance-UGA. Progeny seeds are bulked by selfing and sent out to six partner countries for testing and evaluating for yield and other traits of interest such as disease and pest resistance. Pedigree and genomic information are used to analyse genomic breeding values for grain yield, seed size, CKT, Fe and Zn in the progeny from the two crossing programs.

In 2023, for the first time since COVID prevented international travel, we undertook face-to-face training in the new breeding technology with East African bean breeders, firstly in Uganda in February and then in Uganda and Rwanda in October. This was highly successful and demonstrated the value of hands-on training for data management and data analysis in crop breeding (see image 1).

Partner countries share data through the BMS (Building Management System) database for selecting progeny for further testing in their region and to advance potential new varieties within their preferred market classes. Subsequently, new bean varieties will be released into relevant markets in East Africa through the Alliance and PABRA networks and with the involvement of African farmers in participatory variety selection.

This research is supported by UWA and the ACIAR Project CROP/2018/132.

ECU Nutrition & Health Innovation Research Institute Post Doctoral Research Fellow Dr Liezhou Zhong with the 3D food printer. Credit: ECU

Three-dimensional food printing: Its readiness for a food and nutrition insecure world

Project team: Dr Liezhou Zhong[2] (project leader; l.zhong@ecu.edu.au), Associate Professor Joshua Lewis[2,3,4], Dr Marc Sim[1,2,3], Dr Catherine Bondonno[1,2,3], Professor Mark Wahlqvist[5,6], Associate Professor Amin Mugera[1], Professor Sharon Purchase[1], Hackett Professor Kadambot Siddique[1], Associate Professor Michael Considine[1], Stuart Johnson[7], Professor Amanda Devine[2], Professor Jonathan Hodgson[1,2]

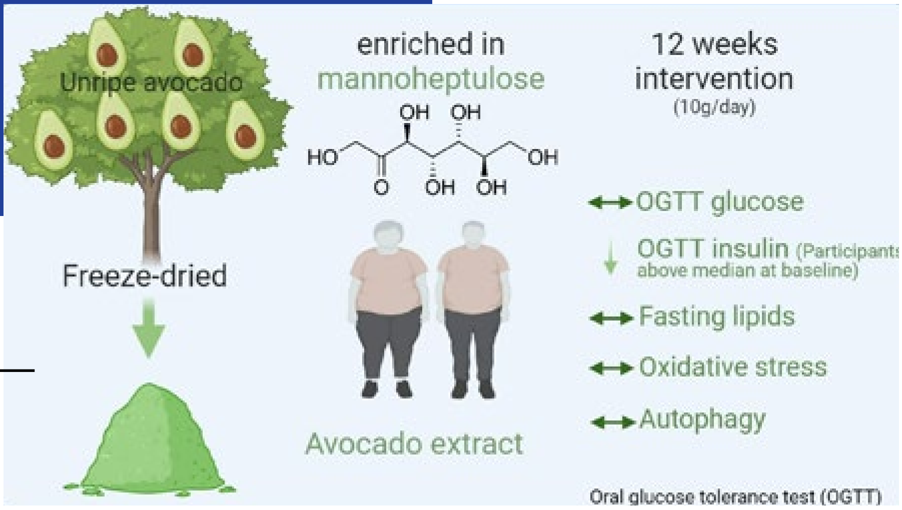
Collaborating organisations: [1]UWA; [2]Edith Cowan University, WA; [3]Royal Perth Hospital Research Foundation, WA; [4]The University of Sydney, Sydney, NSW; [5]Monash University, VIC; [6]School of Public Health, National Defence Medical Centre, Taiwan; [7]Ingredients by Design, WA

Three-dimensional (3D) food printing technology can fabricate food objects layer by layer, from the bottom to the top. The technology can design geometries of food objects guided by computer-aided design models or scanned 3D models. 3D food printing is recognised as a new frontier in the food industry to enable rapid prototyping, customised food design and personalised nutrition. Furthermore, as the world is becoming food and nutrition insecure due to unstable world food supply chains and climate variability, 3D food printers as home appliances could serve as more inclusive and affordable tools to deliver personalised nutrition through localised food supplies and food waste upcycling.

There has been an explosion of 3D food printing publications since 2008, as revealed by bibliometric analyses. While the applications of such technology are far-reaching, its potential to benefit vulnerable communities with chewing and swallowing difficulties by reshaping texture-modified foods (TMF) is exceptionally appealing. Nevertheless, the concepts of using 3D food printing for personalised nutrition and reshaping TMF are often impractical, with multiple inherent technological constraints. Furthermore, with 3D food printing in its infancy, there are unknown impacts on the food system and on human health.

This review focuses on extrusion-based 3D food printing, the most common 3D food printing technology and depicts its current readiness in real-world applications, particularly in human nutrition and health. The project will address the barriers to implementation and means to overcome these to enable the deployment of 3D food printing to improve food and nutrition security and sustainability. Additional consideration was given to consumer acceptance, ethical and regulatory requirements and the cost-effectiveness of 3D food printing, which can ultimately determine its adoption and sustainability.

This research is supported by the Western Australian Future Health Research and Innovation Fund, an initiative of the WA State Government.



The graphical abstract for the study.

Effects of an unripe avocado extract on glycaemic control in individuals with obesity: A double-blinded, parallel, randomised clinical trial

Project team: Adjunct Professor Donald K. Ingram[4] (project leader; donald.ingram@pbrc.edu), Dr Lijun Zhao[2,3], Dr Eric Gumpricht[5], Trent De Paoli[6], Dr Xiao Tong Teong[2,3], Dr Bo Liu[2,3], Professor Trevor Mori[1], Professor Leonie Heilbronn[2,3], George Roth[7]

Collaborating organisations: [1]UWA; [2]The University of Adelaide, SA; [3]South Australian Health and Medical Research Institute, SA; [4]Louisiana State University, USA; [5]Isagenix International LLC, USA; [6]De Paoli Farms, QLD; [7]Prolongevity Technologies LLC, USA

Unripe avocados (*Persea americana*) are naturally enriched in mannoheptulose (MH), which is a candidate caloric restriction mimetic. The objectives were to evaluate the effects of a diet supplement made from unripe avocado on glucose tolerance, and cardiometabolic risk factors in free-living nondiabetic adults with obesity.

In a double-blinded, randomised controlled trial, 60 adults (female n = 47, age 48 ± 13 years, BMI 34.0 ± 2.6kg/m^2) were stratified by sex and randomised to avocado extract (10g finely ground, freeze-dried unripe avocado) or placebo (10g finely ground cornmeal plus five per cent spinach powder) daily, for 12 weeks. The primary outcome was a change in glucose area under the curve (AUC) in response to a 75g oral glucose tolerance test. A post-hoc analysis was subsequently performed in a subgroup with insulin AUC above the median of baseline values after removal of participants >2 standard deviations from the mean.

There were no between-group differences in glucose AUC (p= 0.678), insulin AUC (p= 0.091), or cardiovascular outcomes. In the subgroup analysis, insulin AUC was lower following in avocado extract versus placebo (p= 0.024). Daily consumption of unripe avocado extract enriched in MH did not alter glucose tolerance or insulin sensitivity in nondiabetic adults with obesity, but the data provided preliminary evidence for a benefit in insulin AUC in a subgroup of participants with elevated baseline postprandial insulin levels.

This research is supported by Isagenix (Asia Pacific) Australia, and a CSIRO Innovations Connections grant.

Unripe avocadoes growing on the vine. Credit: Luis Echeverri

Study participants mainly derived Omega-3 fats from marine sources such as fish and shellfish. Credit: Oleksandr Prokopenko

Relationship between dietary intake and erythrocyte polyunsaturated fatty acids in adolescents from a Western Australian cohort

Project team: Professor Wendy Oddy[2] (project leader; wendy.oddy@utas.edu.au), Dr Fuzhen Wan[2], Dr Feng Pan[2], Professor Trevor Mori[1], Associate Professor Therese O'Sullivan[3], Emeritus Professor Lawrence Beilin[1]

Collaborating organisations: [1]UWA; [2]University of Tasmania, TAS; [3]ECU; CSIRO

Population-based studies show that the intake of omega-3 (n-3) and omega-6 (n-6) polyunsaturated fatty acids (PUFA) are associated with a range of health conditions. Therefore, the reliability of food frequency questionnaires (FFQ) as rapid and easily accessible screening tools for PUFA intake deserve investigation.

We aimed to assess the relationship between erythrocyte fatty acids and fatty acid intake collected using the CSIRO food frequency questionnaire from 1155 young adolescents participating in the 14-year follow-up of the Raine Study. Statistical analysis used Bland–Altman plots to determine the agreement between dietary intake and erythrocyte levels of each fatty acid.

The main dietary source of n-3 long-chain (LC) PUFA was 'fresh fish' (53 per cent of total n-3 LC-PUFA). Docosahexaenoic acid (DHA) mainly from fish, showed the strongest correlation between erythrocyte and diet assessment ($r = 0.274$; $p < 0.001$). In contrast, linoleic acid (LA) ($r = 0.103$; $p < 0.001$) derived mainly from vegetable and seed oils, and arachidonic acid (AA) ($r = -0.06$; $p = 0.042$) showed weaker correlations, with limits of agreement relatively narrow. The analyses showed a dose-dependent bias between the FFQ fatty acid data and corresponding erythrocyte data.

For the major n-3 and n-6 PUFA, dietary intakes derived from the FFQ showed weaker correlations and poorer agreement with erythrocyte levels, and the deviation between the two increased with higher intake levels.

This research is supported by The Raine Study, which is core-funded by UWA, Curtin University, Telethon Kids Institute, Women and Infants Research Foundation, ECU, Murdoch University, The University of Notre Dame Australia, the Raine Medical Research Foundation and the National Health and Medical Research Council of Australia.

The Raine Study, based at UWA, is one of the world's oldest and longest-running pre-birth longitudinal cohort health studies.

UWA students Ewen McCabe, Agyeya Pratap and Owie McCarthy collecting hyperspectral measurements of wheat flag leaves with the ASD FieldSpec 4. *See page 105*

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Engineering for Agriculture

The Engineering for Agriculture theme focuses on providing engineering solutions to agriculture for sustainable growth of net farm yield, reduction of wastage, and minimisation of environmental impact. As we head towards 2050 and face the need to feed 50 per cent more people on fewer resources, food production efficiency will become increasingly important and highly dependent on advances in agricultural engineering (ag-engineering).

This theme brings together ag-engineering-related teaching and research across the whole of UWA, enabling us to respond efficiently to new challenges and opportunities as they arise. This theme also presents extensive opportunities for collaboration between farmers, agricultural machinery manufacturers and the IOA, to undertake research and development focused on bringing about commercial innovation.

Theme Leaders

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Members of the CEI:AgER team at their evokeAg stall.

Dr Monte Masarei presenting to Kimberly Rangers visitors.

Centre for Engineering Innovation: Agriculture & Ecological Restoration

Project team: Associate Professor Andrew Guzzomi[1] (project leader; andrew.guzzomi@uwa.edu.au), Professor Michael Walsh[1,2], Dr Todd Erickson[1], Trent Mahony[1], Dr Carlo Peressini[1], Dr Monte Masarei[1], Dr Wesley Moss[1], Dr Luke Omoarelojie[1], Dr Shanika Harshani[1], Dr Stuart Watt[1], Lee Hunt[1], Yvonne Zago[1], William Richards[1], Stephanie Lye[1], Eve McCallum[1], Ruby Wiese[1], Harrison Caddy[1], Yuval Juran[1], Erwin Bauernschmitt[1]

Collaborating organisation: [1]UWA; [2]Charles Sturt University

In its second full year since it was founded in late 2021, the Centre for Engineering Innovation: Agriculture & Ecological Restoration (CEI:AgER) at UWA Shenton Park Field Station continues to build upon its strong relationships with innovative farmers and industry groups and sustained track record of solving interdisciplinary challenges facing the agricultural and environmental sectors. The Centre's mission is to provide engineering solutions and methodologies for agricultural prosperity and ecological restoration. With practicality, commercialisation, and easy adoption in mind, the team aims to enhance the social value, economic value, and sustainability of agricultural and environmental resources.

CEI:AgER's expertise is multidisciplinary and spans areas including engineering, plant biology, agronomy, animal production, and ecosystem restoration.

Highlights from 2023 include:

- The CEI:AgER team expanded with the addition of four post-doctoral researchers with diverse skillsets across seed science, ecology, software engineering, physics, mechanical design and simulation.
- Weed Tech Theme Lead Professor Michael Walsh was awarded Professorship at Charles Sturt University.
- The team hosted the UWA stall at AgriFutures evokeAg 2024 in Perth, where innovations such as the Seed Flamer, Weed Chipper and novel site specific in-crop weeding tool were showcased at Asia-Pacific's biggest AgriFoodTech Conference.
- Ag Tech Theme Lead Dr Wesley Moss returned to UWA after completing a Fulbright Fellowship as a visiting researcher at North Carolina State University and USDA.
- Honours student in CEI:AgER Caleb McKenna was awarded Rhodes Scholarship to undertake a PhD at the University of Oxford.
- Centre Director Associate Professor Andrew Guzzomi was awarded the Mid-Career Research Award from the School of Engineering.
- Dr Moss was awarded the 2023 UWA Award for Excellence in Teaching – Early Career.
- Numerous visitors to the CEI:AgER headquarters at the UWA Shenton Park Field Station: Sher-e-Kashmir University of Agricultural Sciences and Technology-Jammu, Minister for Energy, Environment, and Climate Action the Honourable Reece Whitby MLA, Argentinian Machinery Industry Trade Mission to Australia, Nagoya University, Kimberly Rangers, and US Weed Scientists.

This research is supported by UWA.

Dr Wesley Moss in North Carolina working with the Precision Sustainable Agriculture network as part of his Fulbright Fellowship.

Testing of the protype weed control device at the Shenton Park Field Station.

Mechanical in-crop weed control

Project team: Associate Professor Andrew Guzzomi[1] (project leader; andrew.guzzomi@uwa.edu.au), Professor Michael Walsh[2], Dr Carlo Peressini[1], Dr Stuart Watt[1]

Collaborating organisations: [1]UWA; [2]Charles Sturt University

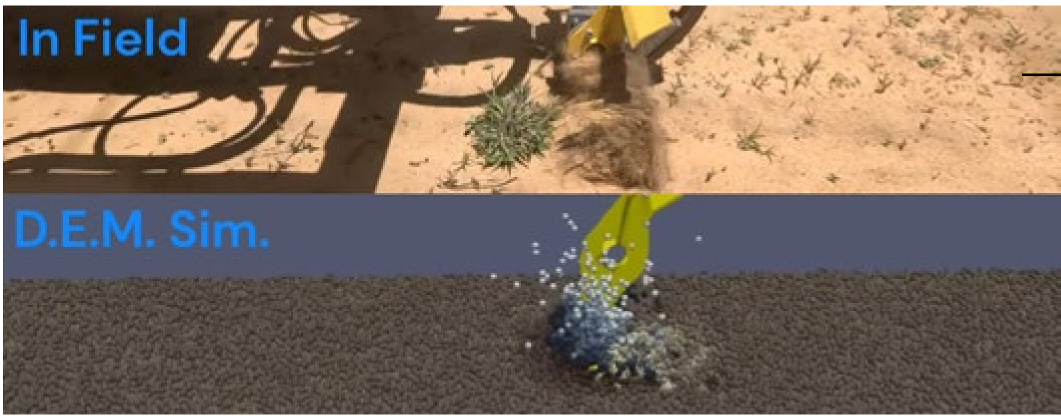
The aim of this project, which is funded by the Department of Agriculture, Fisheries and Forestry, is to develop a mechanical weed control system for use in-crop in large-scale row-crop farming systems. With skills in engineering and weed science, the team is working with leading farmers/innovators, industry partners and machinery manufacturers in WA, NSW and QLD to devise adoptable solutions.

This work builds on the work of the initial Weed Chipper project which was developed as a targeted tillage system for fallow weed control and was funded by the GRDC.

Herbicide resistance is estimated to cost farmers $108 million annually and threatens crop yields, ultimately threatening Australia's food security. There are currently no alternatives to herbicides for weed control in large-scale crop farming. This project aims to add another tool to the weed control arsenal, that allows for non-chemical methods by mechanically removing weeds from the field in-crop.

Highlights of 2023 include the appointment of Dr Stuart Watt as a Research Fellow in the project and the patent of a new in-crop mechanical weed control implement showcased at evokeAg 2024.

This research is supported by UWA and the Department of Agriculture, Fisheries and Forestry.



Simulation of the prototype weed control device.

Associate Professor Andrew Guzzomi with an inverted sub clover sward prepared by the swathing prototype.

Building new tech for sustainable sub clover seed harvesting

Project team: Associate Professor Andrew Guzzomi[1] (project leader; andrew.guzzomi@uwa.edu.au), Professor Megan Ryan[1], Associate Professor Phillip Nichols[1], Dr Wesley Moss[1], Ruby Wiese[1], Joe Shaw[1], Bradley Wintle[1], Dr Ann Hamblin[1], Lee Hunt[1], Minnie Meng[1], Adrian Tsoi[1], Yvonne Zago[1]

Collaborating organisation: [1]UWA

This project aims to build and test new technologies that can be adopted for the sustainable and profitable harvesting of sub clover seed. This follow-on AgriFutures project builds upon the extensive knowledge base and relationships developed through the predecessor 'Profitable and Environmentally Sustainable Sub Clover and Medic Seed Harvesting' project. The research team, comprising skills in agricultural engineering, pasture agronomy and plant physiology, is working with a range of leading seed growers and pasture seed companies in WA, SA, NSW and Vic to address seed production issues.

Subterranean clover (or sub clover) is Australia's most widely grown annual pasture legume and is considered the backbone of Australia's sheep and beef pastures. Australia is the world's largest producer and exporter of sub clover seed, but its global supply is threatened by challenges facing the seed production industry. The industry is currently reliant on suction harvest technology that is slow and takes a heavy toll on the soil. To introduce new technology that can address some of these issues, the research is investigating a swathing approach that harvests sub clover seed without suction and causes significantly less soil disturbance.

The multidisciplinary project team is conducting research across engineering, agronomy and economics to understand how new approaches will affect the plant's biology and the impacts on the seed production industry.

Recent research highlights include testing of new swathing approaches and modifications to existing Horwood Bagshaw vacuum harvester at UWA Shenton Park Field Station, UWA Farm Ridgefield and at commercial seed production sites.

This research is supported by UWA and AgriFutures Australia.

Dr Wesley Moss in dusty conditions testing the status quo suction based Horwood Bagshaw Clover Harvester.

Ruby Wiese aiding in-field tuning of prototype machine for swathing subterranean clover during trial at UWA Farm Ridgefield in October 2023.

Experimental plots of subterranean clover at the UWA Shenton Park Field Station in September 2023.

Evaluation of the agronomic performance of novel methods for sustainable subterranean clover (*Trifolium subterraneum* L.) seed harvesting

Project team: Ruby Wiese[1] (project leader; ruby.wiese@research.uwa.edu.au), Professor Megan Ryan[1], Associate Professor Andrew Guzzomi[1], Associate Professor Phillip Nichols[1], Dr Wesley Moss[1]

Collaborating organisation: [1]UWA

Subterranean clover (*Trifolium subterraneum* L.) is an invaluable annual pasture legume for Australian agriculture with the unique trait of burying its seeds below-ground. While desirable for pasture persistence, this trait makes harvesting the seed difficult. Current seed harvesting practice revolves around the Horwood-Bagshaw Clover Harvester and although effective, the process is inefficient, can degrade soil and cause erosion, and relies on ageing, outdated harvesters. Swathing is an alternative harvesting method which addresses these issues. Before plants have fully senesced, plant roots are cut, plants lifted and windrowed so that dried plants can be harvested with a combine.

Ruby Wiese's PhD aims to investigate the feasibility of a swathing approach for harvesting subterranean clover.

A key consideration of effective swathing is timing: swathing too late when plants are dry and brittle results in poor seed retention, yet swathing too early may result in decreased yield and collection of immature seeds with poor quality. Hence, Ms Wiese has investigated changes over time during seed maturation of seed yield and quality, as well as seed retention during swathing.

To date, she has examined yield, seed quality, and indicators of plant development stage for six subterranean clover cultivars on 10 harvest dates covering October 2023 to February 2024, and data are currently undergoing analysis. Ms Wiese plans to use these data to develop an identification system for the ideal swathing window which maximises collected seed yield and quality. Additionally, she has planned an experiment to examine whether the addition of water to fully mature and dried subterranean clover plants will increase the ductility and integrity of stems and peduncles, thereby increasing retention of seed-containing burr during swathing. Such a technique may allow effective swathing of fully mature plants, resulting in high yield and quality.

This PhD project forms part of a larger AgriFutures Australia-funded project (see page 100) investigating novel methods for harvesting subterranean clover seed which address the shortfalls associated with the current Horwood Bagshaw process. Development of a more efficient harvesting method will make this pasture legume more accessible globally. As sub clover offers nitrogen fixation, high nutritive value, and strong persistence due to hardseededness and high tolerance of heavy grazing, more widespread establishment and frequent renovation of sub clover-based pastures represents a significant benefit to livestock and cropping systems around the world.

This research is supported by UWA, AgriFutures Australia, the Australian Government Research Training Program Stipend, and an AW Howard Memorial Trust Research Fellowship.

Restored landscape 20 months post seeding.

Seedling from restoration trial.

Restoration Engineering Seed Technology Deployment Program and Australian Seed Scaling Initiative

Project team: Dr Todd Ericson[1] (project leader; todd.erickson@uwa.edu.au), Associate Professor Andrew Guzzomi[1], Dr Monte Masarei[1], Dr David Merritt[2], Dr Shanika Harshani[1], Dr Luke Omoarelojie[1], Harrison Caddy[1], Eve McCallum[1]

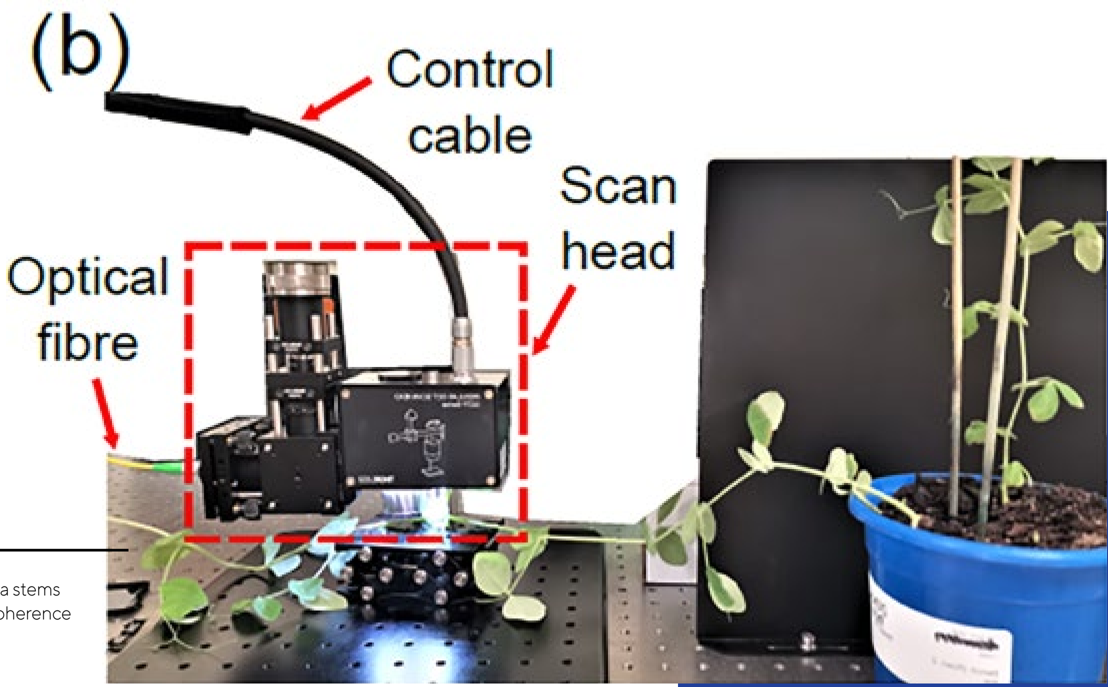
Collaborating organisations: [1]UWA; BHP; Alcoa; CRC TiME; Botanic Gardens and Parks Authority; [2]Department of Biodiversity, Conservation and Attractions

Accurately and efficiently using wild-collected native seeds to initiate plant establishment is a critical challenge to large scale ecological restoration and rehabilitation. As climate change reduces the availability of viable seed stock, current failings and inefficiencies in native seed handling and planting will impact restoration outcomes more severely. Therefore, increasing the efficiency of seed performance in ecosystem rehabilitation for mined and agricultural landscapes is paramount to ensure positive restoration outcomes.

These two projects work to develop technology and systems to process, enhance and more efficiently precision sow diverse mixes of wild-collected seeds. This work extends across the spectrum of seed enhancement techniques (e.g. the CEI:AgER developed Seed Flamer) to new methods to effectively sow seed.

The engineers and scientists at CEI:AgER in the project team collaborate extensively with seed scientists at Kings Park Science. In 2023 the ecological restoration team grew significantly with the appointment of Dr Shanika Harshani, Dr Luke Omoarelojie and Harrison Caddy as well as PhD candidates Eve McCallum and Steph Lye.

This research is supported by UWA, BHP and CRC TiME.



Measuring pea stems with optical coherence tomography.

Engineering and medicine provide a breakthrough in measuring pea stem walls *in vivo* with optical coherence tomography

Project team: Dr Qi Fang[1,2] (project leader; qi.fang@uwa.edu.au), Associate Professor Dilusha Silva[1] (project contact; dilusha.silva@uwa.edu.au), Felix Haederle[1], Felipe Castro-Urrea[1], Professor Wallace Cowling[1], Dr Rowan Sanderson[1,2], Professor Brendan Kennedy[1,2]

Collaborating organisations: [1]UWA; [2]UWA Harry Perkins Institute of Medical Research

In this collaborative project across UWA in engineering, medical engineers and agriculture, we developed optical coherence tomography to measure the thickness of field pea stem walls in living plants. Field pea stems are thin cylinders which lack strength, and consequently pea plants tend to fall over (lodge) before harvest. Pea breeders aim to increase the thickness of stems and reduce lodging through selection. Optical coherence tomography (OCT) has mainly been developed and used in biomedical applications, such as ophthalmology, oncology and cardiology but several preliminary studies have shown that OCT can also provide non-destructive measurements of plants in agricultural applications. We set out to determine if OCT can be used to measure stem thickness in living pea plants.

In vivo OCT measurements of stem wall thickness had an average percent error of −3.1 per cent when compared with *ex vivo* measurements. Additionally, we performed OCT measurements of both stem wall thickness and stem width at various internode positions on two cultivars, Dunwa and Kaspa. The results revealed that Dunwa had a uniform stem wall thickness across different internode positions, while Kaspa had a significantly negative slope of −0.0198mm/node. Both cultivars exhibited an increase in stem width along the internode positions; however, Dunwa had a rate of increase of 0.1844mm/node, which was three times higher than that of Kaspa.

OCT was efficient for accurate *in vivo* measurement of the stem wall thickness in living field pea plants. Moreover, OCT showed different trends of stem wall thickness and stem width along the internode positions in two cultivars, potentially resulting in differences in their stem strength. This rapid, *in vivo* imaging method provides pea breeders with a useful tool for characterising physical traits critical in breeding cultivars that are resistant to lodging. Findings from this research were published in *Plant Methods* in 2023.

This research is supported by UWA, the Australian Research Council, Raine Medical Research Foundation, and National Breast Cancer Foundation.

Flight-path mapping with three drones.

Drone swarms for agriculture

Project team: Associate Professor Dilusha Silva[1] (project leader; dilusha.silva@uwa.edu.au), Dr Michal Zawierta[1], Joshua Bennett[1], Hannah Page[1], Isabelle Abrahams[1], Myles Kelly[1]

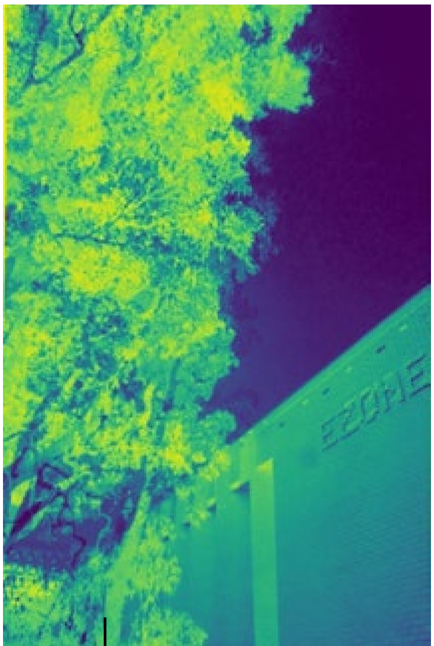
Collaborating organisation: [1]UWA

The UWA Aviation Laboratory (UWAAL) operates with the mandate of creating low-cost open drone-designs for agriculture. An issue faced by drone users is the limited payload size and flight time, particularly with the more manoeuvrable multi-rotor drones. To address these limitations, the team is examining the use of drone-swarms to service cropping activities, with each drone dedicated to a specific area or activity. In 2023, UWAAL initiated a project to investigate designs for demonstrating open drone swarm designs. The project was driven by four Master's students, each working on a separate activity of:

1. Sensor payload development,
2. Spray payload development,
3. Drone swarm communication architectures, and
4. Route optimisation.

Together, these components would allow an integrated drone swarm to identify targets in the crop, assess the required spray treatment, and navigate the appropriate drone to implement the treatment at the target location. This project will continue into the next year with the next crop of MPE project students.

This research is supported by the UWA School of Engineering and Australian National Fabrication Facility.



NDVI image obtained with senor payload to identify targets in crop.

Earthquakes in the Western Australian wheatbelt

Project team: Victor Dent[1,2] (project leader; vic_dent@yahoo.com), David Love[3], Paul Harris[4]

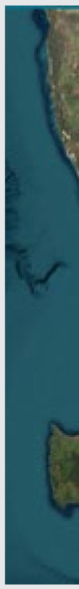
Collaborating organisations: [1]UWA; [2]Geoscience Australia; [3]Seismological Society of Australia; [4]Australian Centre for Geomechanics

The wheatbelt region of South West Western Australia is possibly the most active seismic region in Australia and has seen the destruction or severe damage of three wheatbelt towns (Meckering 1968, Calingiri 1970, and Cadoux 1978). This current project aims to place additional seismographs in useful locations, so that smaller seismic events can be detected, and more precise locations made for large events. This will hopefully lead to the identification of seismically active faults in the region – none have been positively identified yet.

Victor Dent's earthquake monitoring network includes about 10 sensors in the wheatbelt, including one at UWA Farm Ridgefield (since 2015). This instrument has enabled locations for earthquakes in the wheatbelt to be made with more precision. It also allows more closely monitoring of two relatively active seismic centres nearby – about 30km NE of Pingelly, and another centre west of Brookton.

In November 2023, Mr Dent presented a paper to the Australian Earthquake Engineering Society in Brisbane on the continuing seismicity from the Arthur River area. While a consensus on the distribution of seismicity there is yet to be reached, the paper suggested the events were more closely spaced than previous locations suggest, had a possible NNE orientation, and were probably only about 3km deep.

This research is supported by the Seismological Society of Australia and Australian Centre for Geomechanics.



A LICOR-6400/XT portable photosynthesis system set up, ready to measure wheat flag leaf photosynthesis.

Acceletrait: Accelerated integration of physiology-based wheat traits within a commercial breeding programme

Project team: Associate Professor Nicolas Taylor[1] (project leader; nicolas.taylor@uwa.edu.au), Dr James Kelly[1], Agyeya Pratap[1], Owie McCarthy[1], Ewen McCabe[1], Dr Cathrine Ingvordsen[2], Dr Anton Wasson[3], Dr Fernanda Dreccer[3], Dr Gonzalo Estavillo[3], Dr Alec Zwart[3], Professor Owen Atkin[4], Daniel Cowan-Turner[4], Dr Andrew Scafaro[4], Dr Abdeljalil El Habti[5]

Collaborating organisations: [1]UWA; [2]Australian Grain Technologies; [3]CSIRO; [4]Australian National University, Canberra; [5]University of Adelaide; GRDC

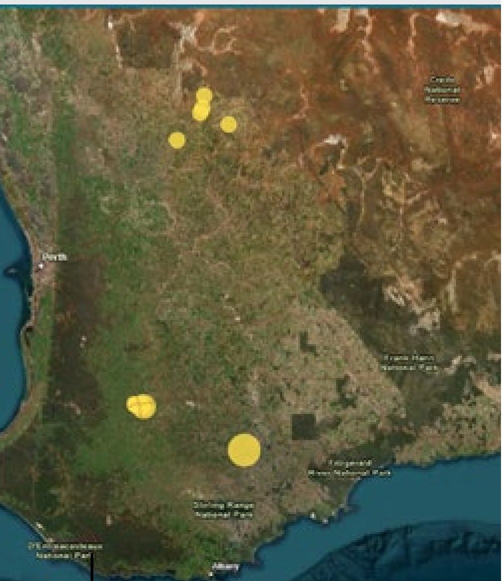
There has been a significant amount of research directed towards understanding the physiological and biochemical processes in wheat and ultimately optimising these traits to increase grain yield. However, the correlation between these traits and grain yield, as well as their interaction with the environment, remains unclear. This project involves collaborations between academic researchers across Australia as well as the wheat breeding company, Australian Grain Technologies (AGT), to explore and assess a variety of physiology-based traits associated with early growth, photosynthesis, and yield. This project aims to focus on optimising high throughput methodology for validating selected physiology-based traits within breeding trials with the goal of leading towards transformational yield improvements, particularly in water limited conditions.

In 2023, teams from UWA, CSIRO, ANU and AGT underwent a field campaign with the goal of data collection of high impact traits, including flag leaf photosynthesis, respiration, and rate of grain filling, at different stages of wheat maturity. This data, along with hyperspectral data collected from wheat flag leaves using a high throughput spectroradiometer, was collected throughout the field campaign from a wheat population representing the span of genetic diversity for each of the high impact traits.

The hyperspectral data collected from the 2023 field campaign, as well as future campaigns, will be run through the online 'Wheat Physiology Predictor' platform to acquire predicted flag leaf respiratory and photosynthetic parameters using machine learning. The results of the data collected from the field campaign will provide the opportunity to compare the identified genetic variation of the selected traits for the measured wheat lines with existing genetic variation for these traits in elite Australian germplasm. This comparison aims to accelerate the adoption of the most valuable physiology-based traits by Australian wheat breeding programs. By implementing high throughput methodologies for assessing high impact traits, it will make it more valuable for wheat breeding companies to adopt these traits in their programs, ultimately leading to the delivery of wheat varieties with significantly enhanced water-limited yield potential to Australian growers.

This research is supported by the GRDC.

Fracture in granite pavement at Arthur River possibly related to seismic activity.



Larger earthquakes (Magnitude 3.0 or greater) in SW West Australia since January 2023.

A man works in a rice paddy in rural Bangladesh overlooked by a makeshift scarecrow. Credit: Ariful Haque

6

Agribusiness Ecosystems

The agribusiness ecosystem is about the interconnectedness and linkages of agricultural enterprises with each other and with non-agricultural enterprises in the exchange of goods and services. The essence of the ecosystem is the creation of economic value, which is the focus of every commercial activity.

The term 'ecosystem' has its roots in biology. It represents an interaction of living organisms in conjunction with the non-living components of their environment such as water, soil, minerals, and air. The ecosystem exists because of the interconnectedness and relationships between and among the components in the system and their implied interdependencies. Therefore, the robustness of an ecosystem will depend on the strength of the bonds and interrelationships of the components or entities in the community.

The same is true with the agribusiness ecosystem. Agribusiness encompasses all the various business enterprises and activities from the supply of farm inputs, on-farm production, manufacturing, and processing to distribution, wholesaling, and retailing of agricultural produce to the final consumer. All those business enterprises along the value chain are interconnected. The success of any agribusiness firm does not depend only on how efficiently and effectively it is internally managed, but also on how it effectively co-opts the complementary capabilities, resources, and knowledge of the network of other firms and institutions in the same industry and beyond. This includes doing business with non-agricultural oriented businesses in banking and insurance among others and receiving services from government and educational institutions.

The aim of the Agribusiness Ecosystems theme at The UWA Institute of Agriculture is to advance scholarship on socio and economic issues affecting agriculture locally in WA, at the national level in Australia, and globally in other developed and developing countries. The team of scholars and professional experts in this theme address issues related to the governance, productivity, profitability, and sustainability of agribusiness enterprises and industries by providing innovative policy solutions through research, education, training, and capacity building.

Here we provide highlights of research and training activities delivered through the Agribusiness Ecosystems theme in 2023. Our research focus contributes to the realisation of the 2030 Agenda of Sustainable Development.

Theme Leaders

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Professor Sharon Purchase
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Emanuel Gomez (pictured in Northam) interviewed farmers across the wheatbelt.

At the 2023 Liebe Group Spring Field Days in Dalwallinu WA, where Emanuel Gomez promoted the survey and engaged with local farmers.

Investigating the economics underpinning traceability investment decisions of Australian grain sustainability credentials

Project team: Emanuel Gomez[1] (project leader; emanuel.gomez@research.uwa.edu.au), Associate Professor Michael Burton[1], Associate Professor Amin Mugera[1], Professor Ross Kingwell[1,2]

Collaborating organisations: [1]UWA; [2]AEGIC; CBH Group; GRDC; Grower Group Alliance (GGA) SW WA Drought Hub

This PhD research project features an economic analysis to inform the grain industry of WA about key aspects underpinning traceability investment decisions aimed at reporting on grains' sustainability credentials. The project builds on the assumption that traceability systems can secure long-term market access and create conditions that allow growers to capture additional value when marketing their grains.

Traceability is likely to become a prerequisite for market access or a means to extract premiums from consumers who highly value and require verification of certain attributes. Acknowledging this, the study sets out to assess consumers' valuations of the sustainability credentials of grain-based foods, particularly examining the implicit prices of these attributes in Asia, a key export destination for Australian grains. Using data from a new global product database, we aim to identify trends around label claims and the price premiums associated with various sustainability credentials. This will categorise valued attributes where traceability can support their integrity. This study involves collaboration with the Australian Export Grain Innovation Centre (AEGIC), who will provide the dataset and analytical guidance.

Secondly, the research will elucidate a value proposition for a traceability system aimed at reporting on two central aspects of WA sustainability credentials: maximum residue levels and GHG emissions traceability. The objective is to quantify the investment associated with these systems and perform an economic analysis depicting alternative scenarios reflecting potential demand responses at key market destinations for Australian grain exports. This case study, in collaboration with Co-operative Bulk Handling (CBH), aims to identify fit-for-purpose traceability systems for grains targeting high-end demands, enabling marketing differentiation. It will also evaluate how additional benefits that could emerge are distributed among the different actors in the grain supply chain.

Finally, we set out to investigate grain growers' likely adoption behaviour of farm-level technologies that facilitate information provisioning to verify the sustainability credentials of grains. Supported by the South-West WA Drought Resilience Adoption and Innovation Hub (SW WA Hub), we recently completed a survey in WA through which we obtained 82 responses to assess WA grain growers' likely adoption of information-sharing technologies. Farm-level traceability adoption is critical, as farm data sharing is anticipated to be a key source of information to sustain the sustainability credentials of grains.

This study aims to enhance understanding of how traceability may serve as a defensive investment to secure market access or an offensive investment to create additional value through product differentiation. Increasing the value of Australian grains through improved prices and market access is paramount, especially as climate change is likely to limit yield gains that boost Australia's crop production.

This research combines analyses of large datasets of grain-based foods with illustrative case studies and farmer surveys to deepen our understanding of the commercial opportunities surrounding traceability in the grain supply chain. It builds on strategic collaborations with key organisations in the WA grain supply chain, including AEGIC, CBH, and GGA SW WA Drought Hub.

This research is supported by UWA, the GGA SW WA Drought Hub, the GRDC, and AEGIC.

Black Sea Grain Initiative

Project team: Dr David Vanzetti[1] (project leader; david.vanzetti@uwa.edu.au), Dr Ralf Peters[2]

Collaborating organisations: [1]UWA; [2]United Nations Trade and Development (UNTAD)

In response to the Russian invasion of Ukraine on 24 February 2022, grain shipments through the Black Sea were suspended, causing a sharp rise in grain prices and concerns about food security in many developing countries. A United Nations (UN) sanctioned deal, the Black Sea Grain Initiative, allowed trade in food and fertiliser to continue from August 2022. However, that deal was suspended in July 2023, once again putting at risk food security in those countries dependent on grain imports.

As the protracted conflict continued, it remained to be seen what the longer-term impacts might be. Using data provided by UNCTAD and other UN agencies, a global computable general equilibrium (CGE) model was used to assess the trade impacts of the production shortfall in Ukraine plus the Black Sea blockade. We show that with time to adjust, the medium-term price impacts are relatively modest, but the quantity impacts are more significant. Developing country importers are affected more by shortages of coarse grains than wheat or oilseeds. Implications for Australian and other grain exporters are estimated. The role of open international markets is critical to subdue food security concerns. This means that export restrictions need to be kept to a minimum if prices are to be kept down.

A conference paper will be presented in February 2024. Further collaboration with UN agencies (UNTAD) is under discussion.

Ships loading grain on Black Sea.

Black Sea Grain Initiative helps stabilise global grain markets.

RiseWi$e researchers Associate Professor Fay Rola-Rubzen and Dr Fiona Dempster.

RiskWi$e: Behavioural Science Program

Project team: Associate Professor Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Professor David Pannell[1], Professor Marit Kragt[1], Associate Professor Ben White[1], Dr Fiona Dempster[1], Dr Rick Llewellyn[2], Jon Marx Sarmiento[1], Tamara Harold[1], Dr Roy Murray-Prior[3]

Collaborating organisations: [1]UWA; [2]CSIRO; [3]Agribiz RD&E Services

RiskWi$e (the National Risk Management Initiative) is a five-year national initiative of around $30 million that will run from 2023 to 2028, funded by GRDC. It seeks to understand and improve the risk-reward outcomes for Australian grain growers by supporting grower on-farm decision-making.

To achieve this, RiskWi$e will:

1) Involve grain growers in the identification of on-farm decisions that have unknown components of risk-reward that will be studied to elucidate new insights.
2) Develop an improved understanding of the risk-reward relationships for on-farm management decisions.
3) Inform growers and their advisers of new insights into optimising rewards and managing risk.
4) Challenge grower decision-making so future management decisions are evaluated in terms of the probability of upside returns offset against the associated downside risks.

The project is being conducted in partnership with multiple partners, including grower groups, six action research groups, research/extension partners, CSIRO as the national project lead; and the GRDC as the principal partner.

The research program consists of five themes and two overarching body of works: Behavioural Science, and Analytics and Modelling. To deliver RiskWi$e, a participatory action research methodology is being employed.

A combine harvester at work in a Western Australian wheat field.

UWA's Centre for Agricultural Economics and Development (CAED) has been contracted by CSIRO to help deliver the overarching behavioural science component of RiskWi$e by contributing to participatory action research with the Action Research Groups (ARGs) and their stakeholders at the national level.

The research conducted by the UWA Behavioural Science team is part of the National Project Lead (NPLs) activities and will focus on issues or topics common across multiple ARG's nationally where behavioural science opportunities exist to improve risk-reward outcomes for growers.

This will include involving and collaborating with ARGs and the NPLs to meet the objectives of the behavioural science program, which are:

- Build capacity in behavioural science,
- Undertake tracking and baseline studies,
- Raise understanding of learnings and change management opportunities,
- Investigate priority issues or findings where they can help by adding further analysis and insight, and
- Develop extension material to communicate key research findings to industry and stakeholders.

This research is supported by the GRDC.

National partners in the RiskWi$e initiative.

A systematic review of literature on the impact and adoption of laser land leveller

Project team: Sofina Maharjan[1], Associate Professor Maria Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Associate Professor Atakelty Hailu[1], Associate Professor Ram Pandit[1], Dr Jeetendra Aryal[2]

Collaborating organisations: [1]UWA; [2]International Centre for Biosaline Agriculture, United Arab Emirates

Climate change and population growth have exacerbated groundwater extraction for agricultural use. Increasing water use efficiency by reducing water loss during surface irrigation is important for agricultural sustainability, ensuring food security and rural livelihoods. Laser land levellers (LLL) have been promoted as one of the technologies to address water loss in surface irrigated crops, increase agricultural productivity, adapt to climate change, and reduce greenhouse gas emissions.

This paper provides insights into the private and public impact of LLL along with factors affecting ex-ante and ex-post adoption of LLL and gaps in the existing studies showing a comprehensive global picture through a systematic literature review. The review reveals that LLL provides both private and public benefits, including increased yield, revenue, reduced irrigation time, reduced greenhouse gas emissions, and groundwater use.

Factors such as land ownership, secured land rights, stock of service providers, visits made by extension officers, credit access and trained operators influence adoption decisions favourably. Additionally, information from various sources such as extension centres, private traders, progressive peer farmers, and agricultural input sellers was found crucial for LLL adoption. On the other hand, farmers' lack of awareness of the benefits of adopting LLL, low educational levels, non-availability of service providers, high cost of levelling, and small farm size act as barriers to the adoption of LLL. The review highlights that the productivity effect of LLL adoption has not been studied in farmer-managed fields, and adoption decisions have been viewed as a static rather than dynamic process in current studies.

The review suggests the need for secured land and tenure rights, tailoring subsidies to address technology demand heterogeneity, cost-sharing assistance for first-time users and encouraging farmers' participation in local agricultural institutions.

This research is supported by UWA and ACIAR.

Landking laser levelling on dry soil in rural India.

Farmer field visit in Purnea, Bihar, India.

Understanding farm-household management decision making for increased productivity in the Eastern Gangetic Plains – Farmer Behaviour Insights Project

Project team: Associate Professor Maria Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Dr Roy Murray-Prior[2], Professor Renato Villano[3], Professor Kalyan K. Das[4], Associate Professor Md Farid Uddin Khan[5], Dr Krishna P. Timsina[6], Associate Professor S.M. Rahaman[7], Md Mahafuj Alam[8], Jon Marx Sarmiento[1]

Collaborating organisations: [1]UWA; [2]Agribiz RD&E Services; [3]University of New England; [4]Uttar Banga Krishi Viswavidyalaya, India; [5]Rajshahi University, Bangladesh; [6]Nepal Agricultural Research Council; [7]Bihar Agricultural University, India; [8]RDRS Bangladesh

The 'Understanding farm-household management decision making for increased productivity in the Eastern Gangetic Plains', also called Farmer Behaviour Insights Project (FBIP), is a regional project led by UWA from 2018 to 2023. The objective of the project is to understand the decision-making behaviour of farm households on the adoption/adaptation of innovations and the critical factors that influence these decisions.

There were two sequential stages in this project:

1) Examining the value-add of BE in explaining adoption/adaptation decisions of smallholder farmers, and
2) Applying behavioural insights from Stage 1 in designing behavioural interventions and then testing their effectiveness in 'nudging' farmers to adopt/adapt Conservation Agriculture-based and Sustainable Intensification (CASI).

The project completed 32 focus group discussions involving farmers and service providers with 351 participants, 369 key informant interviews, and a baseline survey with 3,444 farmers. Six behavioural experiments including one experiment across all project sites and 5 locale-specific experiments were also conducted, followed by post-intervention survey with 3,542 farmers, an endline survey with 3130 farmers and a post-endline survey with 701 farmers. Results were disseminated through various forms including publications such as journal articles (2), local and international conference presentations (31), reports (4), policy briefs (11), posters (13), working papers series (6), local and national workshops, newsletters, and website. A total of 80 capacity building training were conducted, with a total of 3,799 participants from various government agencies, universities and partner institutions in South Asia. Also, 3,444 farmers participated in various capacity building activities.

The FBIP intervention significantly increased the share of CASI farmers and the share of CASI land area in the Eastern Gangetic Plains, particularly using:

a) Awareness video plus text messaging two weeks before planting, and
b) Awareness video plus text messaging one week after the video plus text messaging two weeks before planting.

Pre-commitment with micro-incentive was associated with a statistically and practically significant increases in CASI land area compared to the control group, and this is evident in both the endline and post-endline period while pre-commitment alone was found not to be sufficient to create significant change in CASI adoption in West Bengal, India.

The behavioural experiments have demonstrated the power of behavioural economics in improving adoption of CASI technologies, showing the pre-conditions for their application to work.

This research is supported by UWA and ACIAR.

Final review workshop held at Bihar Agricultural University.

The first harvest of cabbage intercropped with maize.

Additive intercropping in wide row crops for resilient crop production in Bangladesh, Bhutan and eastern India

Project team: Associate Professor Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Jon Marx Sarmiento[1], Tamara Harold[1]

Collaborating organisations: [1]UWA; International Maize and Wheat Improvement Center (CIMMYT); Bangladesh Agricultural University, Bangladesh; Uttar Banga Krishi Viswavidyalaya, India; Bihar Agricultural University, India; ICAR-Indian Institute of Farming Systems Research, India; Bangladesh Wheat and Maize Research Institute, Bangladesh

Wide-row, additive intercropping offers numerous potential benefits including increased cropping system productivity and profitability; water, labour and energy-use efficiencies; improved household nutrition and food security; women empowerment; and, in the long term, increased soil health. However, to date, there is a paucity of research into wide-row, additive intercropping as distinct from traditional replacement intercropping in South Asian agro-ecologies.

To integrate wide-row, additive intercropping successfully and sustainably into farmers' cropping systems, a range of challenges must first be resolved, including optimal agronomic management and geometry, household and farm-scale implications, and potential off-farm bottlenecks.

This project will identify options for smallholder farmers to sustainably intensify wide-row crop production through the addition of short-duration, high-value intercrop species. The focus is on intensification of wide-row planted crops: primarily dry (rabi) season maize in Bangladesh, eastern India and Bhutan. Other potential main crops will also be considered to examine whether additive intercropping is possible where crops are grown in wide-row spacings and with relatively cool temperatures. While the primary focus of this project is on sustainably improving cropping system productivity, the effects of wide-row, additive intercropping at the smallholder farm level will be considered, including potential food and nutrition benefits for the household.

The project began with an inception workshop held in India in May 2023. Collaborating partner organisations have commenced field experiments in India and Bangladesh, and the socio-economics team (led by Associate Professor Fay Rola-Rubzen from UWA and Dr Wakil Rahman from Bangladesh Agricultural University) are preparing for the baseline survey to be conducted during 2024.

This research is supported by ACIAR.

Attendees at the May 2023 inception workshop in India.

Understanding the drivers of successful and inclusive rural regional transformation: Sharing experiences and policy advice in Bangladesh, China, Indonesia and Pakistan

Project team: Associate Professor Fay Rola-Rubzen[1] (UWA project leader; fay.rola-rubzen@uwa.edu.au), Professor Christopher Findlay[2], Professor Chunlai Chen[2] (ANU project leader), Dr Dong Wang[2], Dr Hue Thi Vuong[1], Curtis Rollins[1], Claire Doll[1], Jon Marx Sarmiento[1], Professor Jikun Huang[3], Associate Professor Yu Sheng[3]

Collaborating organisations: [1]UWA; [2]Australian National University, Canberra; [3]Peking University, China

Rural transformation has been shown to reduce poverty, increase income, and improve food security of rural populations. This international project investigated the role of rural transformation in reducing poverty rates and improving the standard of living for millions of people in developing Asian nations and the impacts of inclusive rural transformation. The research aimed to understand what makes rural transformations successful, the effects of inclusiveness and compare and share insights from countries undergoing different stages of rural transformation – China, Bangladesh, Indonesia and Pakistan - to learn from each other and give tangible advice to policymakers.

This project, led by the Australian National University, is investigating not only the underlying determinants of the stages, speeds and outcomes of rural transformation but also the impacts on institutions, policies and investments (IPIs). UWA Associate Professor Fay Rola-Rubzen led the research on the linkages between gender inclusiveness and rural transformation.

The project held its final project review at the Peking University in China in December 2023. A paper on 'Gender and Rural Transformation: A Systematic Literature Review' was recently published by the *Journal of Integrative Agriculture*.

This research is supported by ACIAR.

Associate Professor Fay Rola-Rubzen presenting a paper on gender inclusiveness and rural transformation at Peking University, China.

The old and the new: Rural transformation in Bangladesh.

Prospects for inclusive value chains: Improving the participation of smallholder farmers in Mindanao, Philippines

Project team: Jon Marx Sarmiento[1], Associate Professor Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Associate Professor James Fogarty[1], Professor Larr N. Digal[2]

Collaborating organisations: [1]UWA; [2]University of the Philippines Mindanao

In the Philippines, one in every four Filipinos is poor. Majority of the poor live in rural areas, particularly in Mindanao, where the top impoverished provinces are located. Mindanao is also home of major export industries including tropical fruits namely, bananas, pineapples, and mangoes. However, the smallholder farmers, landless farm workers, and women farmers in these industries are among the poor. To provide a pathway for the poor to escape from poverty, there is a need to answer the following research questions: To what extent are smallholder farmers participating in high-value chains in the Philippines, and does participation in inclusive value chains lead to poverty alleviation?

A framework of when to use the various comparative advantage indices was applied. The scope included the leading tropical fruits exported by the Philippines globally during the last 25 years, 1997-2021. The Philippine exports of bananas, followed by various products of pineapples including prepared and preserved; fresh and dried; and juice had a comparative advantage while mangoes used to possess comparative advantage using the Normalised Revealed Comparative Advantage index. Using a fixed effects panel regression, a positive association between volume of production and net returns, and a negative association of cost of production to comparative advantage of Philippine tropical fruits was found.

To answer the research question on the extent of smallholder farmers' participation in high-value chains, we utilised a composite indicator to measure the capacity of farmers to participate in high-value chains. The High-Value Chain Participation Index has five indicators comprising the five rural livelihood capital: economic, physical, human, social, and natural. The index was applied to 292 banana and mango farmers in northern and southern Mindanao. Farmers supplying in high-value chains had higher levels of capital compared to farmers supplying in traditional value chains.

The technical efficiency, production, revenue and cost performance of individual contract growers, cooperative contract growers, and growers without a contract were compared. A meta-frontier Data Envelopment Analysis using truncated bootstrapping approach was applied among 186 Cavendish banana farmers. Propensity score matching was used to address the potential self-selection bias. Cooperative contract farmers were more technically efficient than individual farmers and those without contracts, due to their ability to produce quality bananas having price premium resulting in high revenue with a relatively low cost of production. There was a prospect for smallholder farmers, those with low levels of formal education, and resource-poor farmers without financial capital to participate in export value chains through cooperative contract farming arrangements.

Three women inclusiveness indicators were investigated: women as farm operators, if farmers employs women family labour, and if farmers hire women farm workers. The total annual revenue of 340 farmers derived from Cavendish banana production was modelled to determine the effects of women inclusiveness indicators. Ordinary least squares and quantile regression were applied. Hiring more women farmworkers was positively associated with high revenue performance, particularly among the upper-middle group. Applying logit and probit models, we found that farmers who employed women family labour were more likely to hire women farmworkers.

This PhD research is supported by UWA and the ACIAR John Allwright Fellowship, with support from the University of the Philippines Mindanao.

Cavendish banana harvesting in Davao del Norte, Philippines.

A branch of cashew tree grown by smallholder farms in the Central Highland.

Analysis of the efficiency of smallholder farm cashew production in upland areas of Vietnam

Project team: Professor Atakelty Hailu[1], Professor Michael Burton[1], Professor Chunbo Ma[1], Van Cuong Le[1,2] (project leader; vancuong.le@research.uwa.edu.au)

Collaborating organisations: [1]UWA; [2]Vietnamese Academy of Forest Sciences, Vietnam

Upland areas taking up two-thirds of Vietnam's territory are diverse in biophysical and socio-economic conditions. Farming land is often fragmented, hilly, and relatively poor quality. Exported-oriented cash crop production is often a key feature of upland agriculture. In recent years, acknowledging the critical role of tree and crop production for rural livelihoods and agricultural export earnings, the government has launched programs and policies to improve agricultural productivity. However, these governmental efforts have had limited success. Although there have been studies investigating the efficiency of coffee and tea enterprises in Vietnamese uplands, there has been no research on the efficiency of smallholder cashew farms.

This study investigates the degree of productive efficiency and its determinants using farm-level data on smallholder cashew production. It also examines farmers' preferences in relation to government policies designed to influence cashew orchard production practices. The study aims to promote higher efficiency and productivity in upland areas by helping bridge the gap between government policies and smallholder farmer motivation.

The research results highlight that use of improved varieties and maintenance of good soil quality are critical for productivity. In addition, smallholder cashew farms are operating at a significant level of inefficiency, and financial support and credit programs appear useful for improving farmer performance. Some policy implications can be drawn from the research. First, to increase cashew productivity, the government could promote the adoption of improved varieties using grafting techniques and encourage smallholders to selectively maintain cashew orchards on land with good or average soil quality. Second, the government can improve production efficiency by providing farmers with adequate financial support and preferable credit programs with a well-defined monitoring and evaluation scheme.

This research is supported by UWA.

A cashew orchard established by smallholder farms in the Central Highland.

Technological innovations in the Australian wine industry: A study of augmented reality labelling and customer relationship management platform adoption

Project team: Oanh Nguyen[1] (project leader; thikieuoanh.nguyen@research.uwa.edu.au), Associate Professor James Fogarty[1], Associate Professor Michael Burton[1], Associate Professor Amin Mugera[1]

Collaborating organisation: [1]UWA

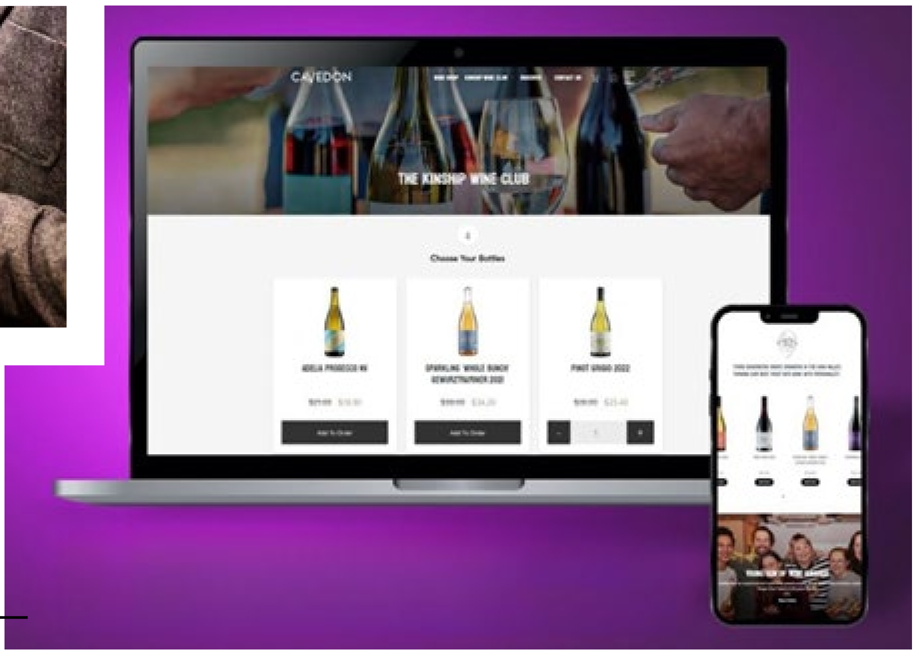
Over the past decade, the Australian wine industry has been subject to many shocks; from drought and water use restrictions that limited production; to covid-19 travel restrictions that limited access to the seasonal workforce needed for harvest; through to politically motivated trade disruptions in what was at the time Australia's largest export market, China, where in 2021 tariffs of between 116 per cent and 218 per cent were imposed on Australian wine. In response to these shocks, Australian wineries have pursued a range of strategies to improve sales in the domestic market and expand sales in non-China markets. Two technological innovations that have been adopted by some Australian wineries are Customer Relationship Management (CRM) software and Augmented Reality (AR) labelling.

CRM technologies enable wineries to develop stronger connections with customers and also allow wineries to gain insights into consumer preferences. A greater connection with consumers allows wineries to sell wines matching consumer preferences and maximise winery return. AR-labelling allows wineries to provide consumers with additional information about the attributes of the individual wine brand the consumer is considering purchasing and provide information on the history and philosophy of the winery. Providing this additional information can increase consumer engagement with the wine brand and translate into an increase in consumer willingness-to-pay for a given wine brand, and greater consumer 'stickiness' for the wine brand/winery for repeat sales. The increase in willingness-to-pay and brand loyalty then results in an increase in firm profit.

There is research on the benefits and costs of CRM and AR-labelling in various industry sectors, but the literature on the impact of CRM and AR-labelling adoption in the Australian wine sector is limited. This research will investigate the impact of the adoption of AR-labelling and CRM in Australian wineries on wine business performance/wine pricing. Study objectives include uncovering the determinates of CRM adoption in Western Australian wineries, exploring consumer preferences for AR labelling, and evaluating how the adoption of the two technologies impacts wine pricing. To achieve the study objectives several methods will be used. Primary data will be collected from both wineries and consumers and this primary data will be combined with secondary data from established wine purchase guides to create a unique database. Formal statistical analyses based on this unique database will be conducted to investigate the relationships between variables and latent constructs. Ultimately, the research outcomes will provide insights that can be used by wineries, academics, and industry organisations to better understanding technology adoption dynamics and pricing impacts following adoption in the Australian wine sector.

This research is supported by UWA and the Australian Research Training Program.

Australian wineries have pursued a range of strategies to improve sales in the domestic market and expand sales in non-China markets.



CRM platform adoption in wine product.

Associate Professor Fang Liu with a range of Karibee Honey products.

The impact of product innovation on brand value and competitiveness

Project team: Associate Professor Fang Liu[1] (project leader; fang.liu@uwa.edu.au), Professor Vincent Chong[1], Yuanyuan Qin[1]

Collaborating organisation: [1]UWA

Product innovation is crucial in agrifood products like honey, but its impact on consumers and brands can be ambiguous. This project examines how innovative products contribute to brand value and competitiveness in the honey industry. Using an Australian honey brand and one of its new products, the study reveals that consumers' perceptions of a honey product's innovativeness directly affect their perceptions of brand value and brand competitiveness.

These research findings offer valuable insights for honey and agrifood producers aiming to boost growth and expansion through product innovation. Australian agrifood products, including honey, are gaining significance in the global food market. Despite this, the full potential of Australian agrifood, especially honey, remains untapped internationally. By understanding consumers' value perceptions, the study highlights the crucial process driving honey product value creation and offers significant implications.

This research is supported by UWA, and Australian Natural Biotechnology provided free product samples used in data collection.

Country-of-origin, region-of-origin or terroir branding to entice premium price? The curious case of geographic place origin construal and psychic distance

Project team: Dr Liudmila Tarabashkina[1] (project leader; liudmila.tarabashkina@uwa.edu.au), Dr Daniel Schepis[1], Professor Sharon Purchase[1], Dr Liz Barbour[2]

Collaborating organisations: [1]UWA; [2]Y-Trace

As a long-studied concept in international marketing, how product place origin influences consumers to prompt purchases, and how this can be leveraged by marketers, remains a topic of great interest. Comparably, much less is known about the effectiveness of more specific place branding strategies, such as region-of-origin (ROO), which identifies smaller geographic areas within countries, and terroir, which goes one step further by linking hyper-specific origin, typicality, history, authenticity, craftsmanship, and legality to convey greater cues to consumers.

Despite firms' long reliance on geographic place origin branding, such as country-of-origin (COO), ROO, and terroir, to sell their products in international markets, little theoretical and empirical work has been carried out to investigate which level of geographic specificity stimulates greater premium price when entering new markets.

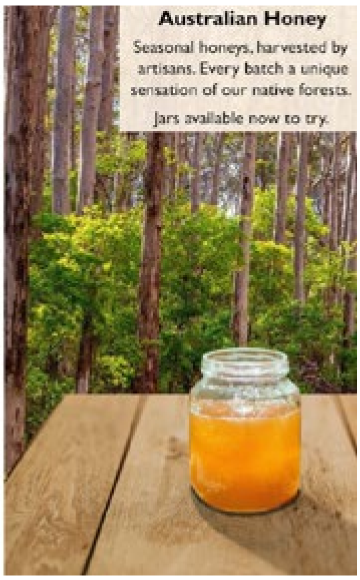
An experiment was conducted in India and Saudi Arabia manipulating place origin as a three-factorial design (COO vs. ROO vs. terroir) using Australia as the country context, and honey as the product context. Honey was chosen to test the hypotheses using an unbranded product to prevent brand familiarity effects. The experiment was conducted in India and Saudi Arabia because Western Australian honey exports to these countries were relatively low (<1 per cent total value) suggesting low awareness especially of terroir. Both countries were also identified as key target markets by the State Government (data provided to researchers by the Department of Primary Industries and Regional Development).

The three experimental conditions featured a consistent core image (a jar of honey on a table) but had varied background and text to manipulate different place origins. In line with current industry usage, the COO stimulus mentioned the country where the product was produced ("Quality honeys, made in Australia. Jars available now to try") and showed an Australian map as the visual representation of COO. The ROO stimulus read as "Quality honeys made in South West Australia. Jars available now to try" and highlighted the South Western region on the Australian map. The terroir stimulus read as "Seasonal honeys, harvested by artisans. Every batch a unique sensation of our native forests. Jars available now to try" and showed a much smaller shaded portion of the South Western region on the Australian map.

Results suggested that COO, ROO, and terroir prompt different place construal, which interacts with psychic distance to people (individual consumer difference), resulting in varying premium price. The study explains under which conditions which of the three place origins benefit companies and which ones backfire.

This research is supported by UWA and the Cooperative Research Centre for Honey Bee Products.

The consistent core images (or 'stimuli') used in the experiment, from left: Country-of-origin (COO), region-of-origin (ROO), and terroir.



A bee visiting a native Grevillea flower. Credit: Georgie Wilson

Terroir Branding Strategy: Opportunities and Challenges for Collective Market Driving

Project team: Dr Daniel Schepis[1], Dr Kim Feddem[3], Dr Liudmila Tarabashkina[1], Professor Sharon Purchase[1], Dr Liz Barbour[2]

Collaborating organisations: [1]UWA; [2]Y-Trace; [3]ECU

This project aimed to understand how industry stakeholders develop an authentic, regional 'terroir' (the complex association between a product and its specific place of production) brand to support value cocreation. This was motivated by a need to examine terroir branding strategies for emerging regions or products lacking established terroir recognition among consumers.

The research team examined an agricultural context (monofloral honey) which fits the characteristics for terroir branding. They developed a case study of the Western Australian monofloral honey industry. Secondary data was collected on 64 local companies via websites and social media accounts, while primary data was collected via 30 interviews with producers, distributors, trade advisors and consumers. Leximancer was used to identify patterns in existing marketing communications, while interviewee narratives were thematically analysed.

These data were used to propose a framework in which terroir dimensions and authenticity dimensions interact with one another, while also highlighting the key barriers preventing coordination of internal and external stakeholders in brand development. They present a case in which collaborative market driving efforts have failed due to competing visions, inconsistent value propositions and a lack of agreement on symbols and meanings shared by agricultural producers about their products, production methods and relationships with place. The research team concludes by presenting an integrated framework of four key challenges marketers and academics should consider when engaging in collective market driving through terroir branding.

This research is supported by UWA and the Cooperative Research Centre for Honey Bee Products.

UWA PhD candidate Jessica Bikaun inspecting a frame. Credit: Prem Bates

Professor Marit Kragt delivering a keynote address to BITA stakeholders.

ARC Industrial Transformation and Training Centre for Behavioural Insights for Technology Adoption

Project team: Professor Marit Kragt[1] (project leader; marit.kragt@uwa.edu.au), Associate Professor Ben White[1]; Associate Professor Steven Schilizzi[1], Dr Fiona Dempster[1], Associate Professor Fay Rola-Rubzen[1], Associate Professor Andrew Guzzomi[1], Dr German Puga[1], Tammie Harold[1], Mahnaz Afsar[1], Yadav Padhyoti[1], Mithun Kumar Ghosh[1]

Collaborating organisations: [1]UWA; Queensland University of Technology; The University of Queensland; Clear Grain Exchange; Dairy Australia; Grower Group Alliance; Agora Livestock; Smart Paddock

Co-operative Australia needs accelerated adoption of innovation technologies to improve outcomes in health, agriculture and cybersecurity. Despite technically viable solutions, innovations fail to be adopted due to behavioural barriers. Behavioural approaches can promote significant gains by bridging the barriers to technology adoption.

The ARC Training Centre for Behavioural Insights for Technology Adoption (BITA) was launched in 2023 to better understand and overcome the behavioural barriers that impede the widespread adoption and diffusion of innovative technologies. In collaboration with industry and government partners, BITA will boost productivity and adoption of innovation, support businesses to grow with people-focused innovation, and enable more innovative new products and services to reach end-users in local, domestic and global markets.

The interdisciplinary team of behavioural economists, psychologists and social marketers will address the challenges at each stage of the innovation process – conception and design, market translation, and evaluation – to improve outcomes in health, agriculture, and cyber-security.

Research projects are currently being designed in collaboration with the industry partners. The UWA team consists of several academic members, a dedicated post-doctoral fellow, and three postgraduate research students.

This research is supported by UWA and the ARC Industrial Transformation Research Program.

Prominent guests (including UWA Vice Chancellor Professor Amit Chakma second from right) inaugurate the NSU-UWA Agribusiness Centre of Excellence.

The official name plaque for the centre.

Agribusiness development research and training at NSU

Project team: Professor Nazrul Islam[1,2] (project leader; nazrul.islam@outlook.com.au), Hackett Professor Kadambot Siddique[1], Associate Professor Amin Mugera[1]

Collaborating organisations: [1]UWA; [2] North South University, Bangladesh

With the joint initiative between the Department of Economics, School of Business and Economics, North South University (NSU) and UWA, a centre of excellence in agribusiness named, 'NSU-UWA Agribusiness Centre of Excellence (ACE)', was officially inaugurated on 31 May 2023 at NSU. The inaugural ceremony was chaired by NSU Vice Chancellor Professor Atiqul Islam and was graced by presence of the Minister for Agriculture the Hon. Dr Muhammad Abdur Razzaque MP, UWA Vice Chancellor Professor Amit Chama, Australian High Commissioner to Bangladesh His Excellency Jeremy Bruer, WA Trade Commissioner for the India-Gulf Region Nashid Chowdhury and visiting academics and delegates from WA universities and industries. On behalf of the Minister for Culture and the Arts, Sports and Recreation, International Education, and Heritage the Hon. David Templeman MLA, Professor Chakma unveiled the name plaque of the centre.

The center aims to foster excellence in agribusiness research and translate its research findings into applied practical outcomes that will have a direct benefit to the agriculture and food industries and impact on food insecurities. NSU board of trustees member Yasmin Kamal, and former Vice Chancellor of Bangladesh Agriculture University Professor M Satter Mandal were also present at the ceremony. The keynote speaker for the event was Professor Dr Nazrul Islam, visiting Professor at NSU and Honorary Senior Research Fellow at The UWA Institute of Agriculture. High Commissioner to Bangladesh Jeremy Bruer graced the session with his presence, emphasising the importance of international collaboration in agribusiness. The event also featured prominent figures from various universities and organisations.

This research is supported by UWA and NSU.

A zoom screenshot during a project research team meeting.

Professor Nazrul Islam sharing preliminary research findings.

Assessing adoption and diffusion of agricultural innovations in Bangladesh

Project team: Professor Nazrul Islam[1,2] (project leader; nazrul.islam@outlook.com.au), Dr Gour Gobinda Goswami[2], Professor Zulfikar Rahman[3], Associate Professor Amin Mugera[1], Hackett Professor Kadambot Siddique[1], Professor Mohamed Quaddus[4], Dr Elizabeth Jackson[4], Dr Fazlul Rabbanee[4]

Collaborating organisations: [1]UWA; [2]North South University, Bangladesh; [3]Bangladesh Agricultural University; [4]Curtin University

Bangladesh faces challenges in agricultural productivity growth, causing slow adoption of agricultural innovations. North South University, Bangladesh Agricultural University, and international partners of Curtin University and UWA are working to address this issue. The project, funded by the Krishi Gobeshona Foundation (KGF) and commissioned in 2021. The project aims to investigate the dominant innovations adopted by farm households and to determine farmers' attitudes, perceptions, intensity and speed of adoption decisions. The Mixed Method, Quality Function Deployment (QFD) and econometric modeling approaches are applied. The project is scheduled to be completed in June 2024. Several activities carried out in 2023 towards completion of the project that are briefly highlighted with some key findings.

Using the mixed method approach and the Technology, Organisation, Environment and Individual (TOEI) theory of technology adoption; and based on the combined findings of the adoption factors identified from a systematic literature review and from several in-depth interviews and focus group discussions of agricultural knowledge experts, a conceptual model of technology adoption was developed and applied for farm household and non-farm stakeholders' survey data collection. Conducting an expert workshop, 14 key strategies were identified to address and mitigate Agricultural Technology Adoption Issues.

Visits of Dr Elizabeth Jackson and Professor Mohammed Quaddus from Curtin University to NSU for a week each on two separate occasions have very successfully facilitated to give hands-on training to the project's Research Associates (RAs) on learning and applying the PLS-SEM and the QFD modeling methods. UWA Associate Professor Amin Mugera provided exceptional guidance to the RAs for econometric modeling and analysis by utilising production data set of the farm household survey.

The PLS-SEM analysis of factors influencing agricultural technology adoption among Bangladeshi farmers by using the TOEI framework suggests that 'Perceived simplicity', 'Source and quality' and 'Low cost and compatibility' characteristics of technology significantly drive adoption directly. As mediators, 'Farmers' capabilities', 'Attitudes', 'Trust', and 'Technology usage skills' were found to be significant. As moderators. 'Market conditions', 'Technology experience', 'Government support', 'Production efficiency', and 'Weather' were important.

A PLS-SEM analysis of the non-farm stakeholders data suggests that 38 factors influencing farmers' agricultural technological adoption in Bangladesh. Utilising the PLS-SEM analysis, mediation, and moderation effects were explored among these constructs. This comprehensive approach enhances understanding of the non-farm stakeholders' view about farmers' technology adoption.

Insights from the analysis of priority policy strategies to enhance agricultural technology adoption in Bangladesh by employing a multi-objective optimisation approach with QFD and the Best Worst Method (BWM) identified 14 groups of strategies to address 14 groups of key adoption issues. Among these the following strategies 'Input support for sustainable yield', 'Address effect of weather and climate change', 'Government support across agricultural supply chain', 'Facilitating good agricultural practices for commercial transition and exports' respectively are found to be the first, second, third and fourth-most important policy strategies to address the problems and issues of technology adoption.

This research is supported by the Krishi Gobeshona Foundation.

International seminar on GMO crops: Policy and practices in Bangladesh

Project team: Professor Sk. Tawfique M. Haque[2] (project leader; tawfique.haque@northsouth.edu), Professor Nazrul Islam[1,2] (project co-leader; nazrul.islam@outlook.com.au)

Collaborating organisations: [1]UWA; [2]North South University, Bangladesh

The question of whether human beings should eat food from genetically modified organisms, and if they should develop and propagate genetically modified (GM) foods is not amenable to a simple 'yes' or 'no' answer. Knowledge of GM food research, and the decision to consume or grow GM food, requires informed choice and decision of the consumers as well as farmers. A review of GMO policy and practices is essential to appreciate the existing gaps in policy, progress on research, and release and commercialisation of GMO products. The main objective of the project is to review the GMO policy of Bangladesh and South Asian countries, and assess current progress in terms of research, production and identify the major challenges.

As part of this project, an 'International Seminar on GMO Crops: Policy and Practices in Bangladesh' was held on 28 October 2023 at North South University aimed at reviewing GMO crop policies, assessing progress, and identifying challenges. It was organised by the NSU-UWA Agribusiness Centre of Excellence, and the South Asian Institute of Policy and Governance at North South University. Distinguished knowledge experts, researchers, policymakers, and stakeholders gathered together and discussed GMOs' impact on agriculture. The event, chaired by NSU Vice Chancellor Professor Atiqul Islam featured a panel of experts including Nobel Laureate Sir Richard J. Roberts, former Secretary of the Ministry of Agriculture Anwar Faruque, and Associate Professor M Mahfuzul Haque.

The seminar discussed the challenges for advancing GMO crops such as misinformation, lack of regulatory framework, environmental risks, resistance in developing countries, biodiversity issues, bio-safety implementation, legal issues, environmental stewardship, time and cost considerations, public awareness, transparency, and lack of empowering consumers and farmers are contributing factors to the growing opposition to GMOs. The seminar also discussed the recommendations for advancing GMO crops.

Keynote speaker Sir Richard J. Roberts, recipient of the 1993 Nobel Prize in Physiology or Medicine.

Additionally, recommendations on awareness strategies on GMO crops were discussed at the seminar were implementing public awareness campaigns about the benefits and safety of GMO technology, collaborating with scientific organisations for educational outreach, advocating for impartial research, promoting informed food choices, stressing the urgency of the situation, launching awareness campaigns, addressing misconceptions, involving influential figures, and encouraging the media to present accurate facts about GMOs, rather than sensationalised narratives, to build public trust in the science behind genetic modification.

This research is supported by the South Asian Institute of Policy and Governance at North South University.

Around the world, there has been much debate about the development of genetically modified crops.

Ord River District Co-operative Ltd – Growing together since 1963

Project team: Emeritus Professor Tim Mazzarol[1] (project leader; tim.mazzarol@uwa.edu.au), Professor David Gilchrist[1], Professor Geoffrey Soutar[1], Associate Professor Andrea Gaynor[1], Associate Professor Amin Mugera[1], Peter Wells[2], Dr Bruce Baskerville[1], Amber van Aurich[1]

Collaborating organisations: [1]UWA; [2]Co-operatives WA; Ord River District Co-operative Ltd

As a part of the ongoing *'Looking Back – Looking Forward: The economic and social contribution of the WA Co-operative and Mutual Enterprise (CME) sector to the state's development'* project, this study explores the history of Ord River District Co-operative Ltd (ORDCO). Founded in 1963, ORDCO is an independent agricultural co-operative located in the Ord River Irrigation Area, Kununurra, Western Australia. It is deeply tied to the history of agricultural development in the Kimberley region.

The study aims to examine the economic and social contribution ORDCO has made in WA, delivering new insights to gain a better understanding and appreciation of the CME sector.

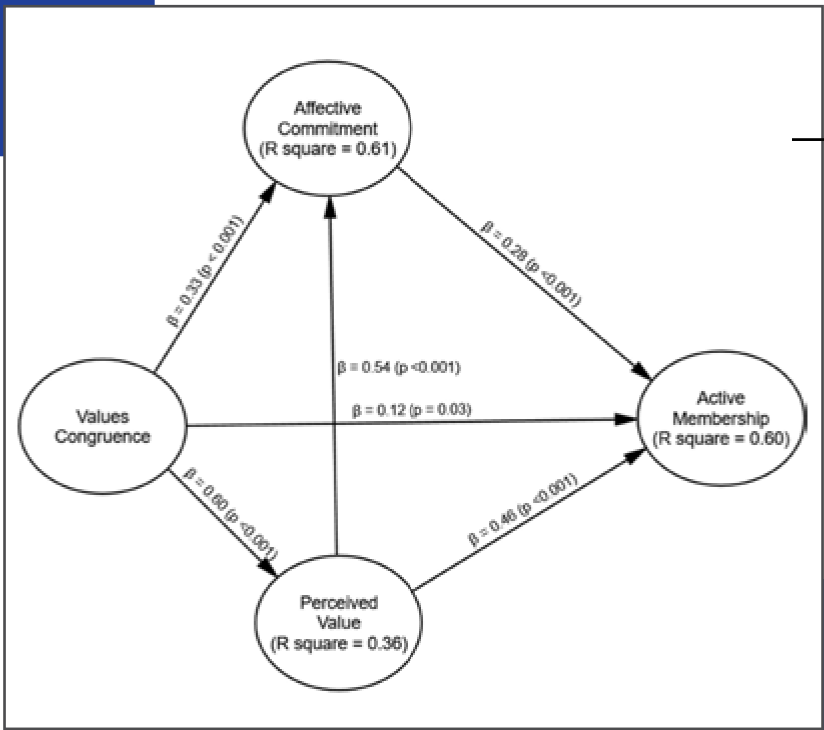
In 2023, the research team travelled to Kununurra, visiting the co-operative in situ to conduct interviews and collect key documents. While there, the team gained a deeper insight into the demands of working in such an ancient landscape. In addition, through the research process, the complicated story emerged of the state's attempts to develop the Ord, specifically through its various stages. It became clear that without the co-operative, agricultural development in the Ord would not exist.

Ord River Diversion Dam in 1963. Credit: Kununurra Historical Society.

Cotton grower Jack Bornholt unloading picked cotton in the 1960s. Credit: Kununurra Historical Society

This study fills existing gaps in the historical record regarding the economic and social contributions of the CME sector to WA. In addition, it highlights the unique demands of agriculture in regional north WA. Moreover, it provides evidence which will help shape policy debate, particularly the impact of legislation and policy decisions by state and federal governments.

This research is supported by UWA, ARC, Co-operatives WA, CBH Group, Capricorn Society Ltd, United Crate Co-operative Ltd, Mount Barker Ltd, Wesfarmers Ltd and The Royal Automobile Club of WA Inc.



The final model of active member engagement.

Values congruence and SMEs' active membership in business co-operatives

Project team: Emeritus Professor Tim Mazzarol[1] (project leader; tim.mazzarol@uwa.edu.au), Professor Shahid Ghauri[2], Professor Geoffrey Soutar[1]

Collaborating organisations: [1]UWA; [2]Curtin University

This research examines how values congruence (person-organisation fit), affective commitment (personal preference for membership) and perceived value (e.g., quality vs price) influence the active membership of small to medium enterprise (SME) owner-managers, who are members of business co-operatives (e.g., those owned by businesses).

A sample of 264 SME owner-manager members was obtained and a path model utilising SEM was used to estimate the relationships between the constructs. Significant relationships were found between all constructs. Values congruence influenced affective commitment and overall value that, in turn, influenced active membership.

The results provide empirical support for suggestions about the factors that influence active membership in co-operatives. Particularly those with SMEs as members. This is beneficial to agribusiness which includes several co-operatives in the sector. It also suggests co-operative managers should focus on ensuring there is a congruency in values with members, rather than solely focusing on members' patronage. Indeed, consistent communications ensures member engagement align value and values between both parties. The paper highlights the importance of co-operatives to be built on the foundation of congruency in value, and value between the co-operative and its members, rather than solely focusing on economic outcomes.

This research is supported by UWA, Co-operatives WA, CBH Group, Capricorn Society Ltd, Geraldton Fishermen's Co-operative, The Royal Automobile Club of WA Inc, Mount Barker Co-operative, and Pure Profile.

Wongon Hills grain harvest in the 1950s. Credit: CBH Group

Sewing wheat bags in Moora, 1938.
Credit: CBH Group

Co-operative Bulk Handling – All members are owners, but 'Nobody owns CBH'

Project team: Emeritus Professor Tim Mazzarol[1] (project leader; tim.mazzarol@uwa.edu.au), Professor David Gilchrist[1], Professor Geoffrey Soutar[1], Associate Professor Andrea Gaynor[1], Associate Professor Amin Mugera[1], Peter Wells[1], Dr Bruce Baskerville[1], Amber van Aurich[1]

Collaborating organisations: [1]UWA; Co-operatives WA; CBH Group

This project is also part of the ongoing *'Looking Back – Looking Forward: The economic and social contribution of the WA Co-operative and Mutual Enterprise (CME) sector to the state's development'* project. It examines the history of CBH Group, going back to the early twentieth century.

CBH Group, also known as Co-operative Bulk Handling Ltd, is one of the largest bulk handling and storage organisations in the world. It is one of Australia's largest grain marketers and exporters, and the only large Australian grain organisation owned and controlled by growers. Founded in 1933, CBH Group has had considerable impact to the development of agriculture in WA over the past ninety years.

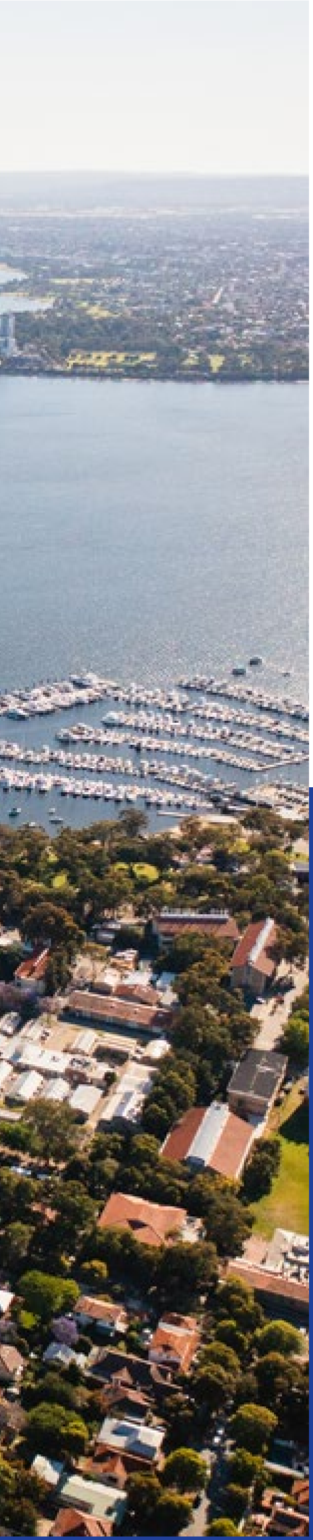
The study aims to examine the economic and social contribution ORDCO has made in WA, delivering new insights to gain a better understanding and appreciation of the CME sector.

In 2023, the research team collected data on CBH's history, including examining its annual reports since 1933. Through data analysis, the research team have explored how CBH Group has overcome the challenges of agriculture in the state's difficult and remote environment, while maintaining co-operative principles, despite intense external and internal pressure to privatise. CBH Group fought for and established necessary agricultural infrastructure, in particular the process of bulk handling and storage. Moreover, government has played a key role in its history, both supportive and as a detriment. Furthermore, the economic and natural environments created challenges and opportunities which shaped CBH Group. The issue of soil salinity is of particular concern throughout the co-operative's history.

This study fills existing gaps in the historical record regarding the economic and social contributions of the CME sector to WA. In addition, it provides evidence which will help shape policy debate, particularly the impact of legislation and policy decisions by state and federal governments.

This research is supported by UWA, Co-operatives WA, CBH Group, Capricorn Society Ltd, United Crate Co-operative Ltd, Mount Barker Ltd, Wesfarmers Ltd, and The Royal Automobile Club of WA Inc.

The UWA Crawley campus on the banks of the Swan River.
Credit: Jarrad Seng



7

Education and Outreach Activities

Strengthening communication links with industry, farmer groups and the broader regional and international scientific communities is one of The UWA Institute of Agriculture's (IOA) key strategies. Several communication channels are used to ensure the University's research in agriculture and related areas is shared with its intended audience. IOA plays an active role in listening to growers, advisors, and agribusiness professionals, to ensure two-way communication and that all ideas and perspectives are considered in the identification of key issues and opportunities.

Front cover and inside spread of the April 2023 newsletter.

Newsletters

IOA's broad range of activities are regularly captured through its newsletter. It is an important channel through which IOA promotes its research outcomes, collaborations, staff and student achievements and upcoming events to key stakeholders, alumni, the agriculture industry, funding bodies and UWA staff.

The newsletter serves as a record of IOA's research activities and captures recently funded projects, research achievements, new staff and students, events and, importantly, a list of newly published peer-reviewed journal articles in agriculture and related areas.

Published three times per year in April, August and December, the newsletter is circulated widely in electronic format and hardcopy to more than 6,000 readers. Feature articles are shared on the UWA Impact website following publication, which reports a large online audience of several thousand views per article. The newsletter also regularly attracts the interest of local media, with select stories being published in *Farm Weekly* and the *Countryman*.

Online presence

The uwa.edu.au/ioa website provides an overview of the IOA vision and mission and is the first point of contact for people searching for information on activities in agriculture and related areas within the University.

Upcoming events are publicised on the website along with a repository of the latest media statements, research and general news. Documents such as the Strategic Plan, Annual Research Report and newsletters are also readily available to view and download.

In 2023, IOA's social media audience increased significantly. The IOA LinkedIn was once again the fastest growing audience, ballooning by 2,053 new followers to a total of 4,907. Thirteen event videos published to the dedicated IOA YouTube channel in 2023 amassed more than 3,434 views. More than 450 people were subscribed to the YouTube channel by the end of 2023. The @IOA_UWA X account (formerly Twitter) gained 524 more followers, to end the year with a total audience of 3,230.

Visitors to IOA

Interactions with members of like-minded institutions, universities, government, and the agricultural industry and community are critical to knowledge sharing and strengthening our research links and collaborations. Throughout 2023, IOA welcomed more than 70 individuals from local, national and international organisations to the Crawley campus.

Seven Nagoya University postgraduate students completed a two-day study tour with UWA academics and external partners including CBH Group, InterGrain, and Australian Export Grains Innovation Centre in February.

In early 2023, the IOA hosted Dr N Anuradha, Assistant Professor Dr V Bhuvaneswari, Dr N Veronica, Associate Professor Venkata Ramana Rao Puram and Dr P Latha from Acharya N.G. Ranga Agricultural University (ANGRAU) for a six-week training program. This included personalised tours of UWA Farm Ridgefield and UWA Shenton Park Field Station, attending Institute-run events, morning teas, special lectures, and forging new connections and working relationships.

The UWA Plant Biology Forum, co-hosted by IOA, enhanced knowledge exchange and fostered further collaborations with esteemed visiting academics from China in May. Visiting academics from seven Chinese universities presented talks on a wide range of topics, including land/soil management,

crop production, agronomy and physiology, root-soil-microbe interactions, and phenotyping and genotyping.

In July, a 30-year reunion tour of the UWA Crawley campus was filled with fond memories, meaningful reconnections, and plenty of laughter for a group of 1993 Bachelor of Agricultural Science graduates. The visit was hosted by emeritus professors Lynette Abbott and Graeme Martin.

The IOA hosted an August workshop on the development and validation of healthy, quality food at the Forrest Research Foundation's Ashburton Room. In addition to UWA leaders, representatives from Vegetables WA, Southern Forest Food Council Inc, Pomewest and more presented from their industry perspectives.

Eight students from Nagoya University visited UWA in September, as organised by Professor Erik Veneklaas. Their busy program included trips off-campus, including visits to UWA Farm Ridgefield, InterGrain, Richgro, Aegic, DPIRD Manjimup, and Boortmalt.

IOA hosted six scholars in the second half of 2023 – their visit featured tours of the glasshouses and plant growth facility chambers, specialised UWA labs, the Shenton Park Field Station, Centre for Microscopy Characterisation and Analysis, and more. Sri Karan Narendra Agriculture University Assistant Professor Malu Ram came for a five-month study tour, Mithraa Thirumalai visited as part of her a PhD at the ICAR-Indian Agricultural Research Institute, and Dr Mahantesha Banvat Nethaji Naika travelled from Bangalore to work alongside Associate Professor Michael Considine.

ICAR-IARI researchers Gayatri Bhimappa Kudari and Anamika Chandel trained in Professor Jacqueline Batley's lab, and graduate student from the University of Agriculture Faisalabad Tahira Rasheed learned new skills and specialisations.

In November, Rani Lakshmi Bai Central Agricultural University (RLBCAU) Vice Chancellor Professor Ashok Kumar Singh and Director of Research Professor Sushil Chaturvedi visited UWA to sign a new Memorandum of Understanding (MoU).

That same month, IOA welcomed Sher-e-Kashmir University of Agricultural Sciences and Technology (SKAUST) delegates visited and agreed upon an MoU for collaboration in areas of mutual interest – including establishing the Master's program and training high quality PhD students at UWA.

During his tour of UWA in December, Director and Vice Chancellor of ICAR-Indian Agricultural Research Institute (IARI) Professor Ashok Kumar Singh visited glasshouse experiments, and attended a meeting with university leaders. Professor Singh then delivered a lecture on 'Molecular breeding for Improvement of biotic stress tolerance & nutritional quality of cereals' to about 40 people at the UWA Bayliss Lecture Theatre.

Photos (clockwise from left):

UWA and Nagoya University leaders and students at Thurling Green.

Nagoya University students visiting grain storage at Boortmalt.

Dr Mahantesha Banvat Nethaji Naika, Tahira Rasheed, Anamika Chandel, Hackett Professor Kadambot Siddique, Professor Jacqueline Batley, Mithraa Thirumalai, Nutan Darandale, Dr Malu Ram.

Professor AK Singh and Hackett Professor Kadambot Siddique with attendees following the lecture.

Hackett Professor Kadambot Siddique, Professor Ashok Kumar Singh, Professor Tim Colmer, Professor Sushil Chaturvedi, Professor Phil Vercoe and Broderick Moncrieff.

Colleagues and students celebrate Hackett Professor Kadambot Siddique's 2023 Scientist of the Year award at an IOA morning tea.

Below photo: Key leaders from UWA and SKAUST, including Vice Chancellors (seated) after signing the MoU.

Mike Carroll Traveling Fellowship

To mark 20 years since the Mike Carroll Travelling Fellowship was established, a video featuring interviews with past and present students was premiered to guests at the 2023 presentation evening in February.

To date, 27 postgraduate students from UWA have benefitted from the Fellowship since the first recipient was awarded in 2003.

It was established in 2001 as a memorial to former Director General of the WA Department of Agriculture Dr Mike Carroll, in recognition of his commitment to agriculture.

UWA guests and friends of the Carroll family attended the special event at The University Club of WA to hear from three of the most-recent Fellowship recipients.

Michael Young has spent his Agricultural Economics postgraduate studies developing a new farm analysis tool to optimise farm management in the face of increased climate variability.

For his Fellowship, he travelled to New Zealand to learn and experience farming outside of his studies and own experiences growing up on a farm in Kojonup.

The second presenter was PhD student Mukesh Choudhary – a researcher from the ICAR-Indian Institute of Maize Research in India researching heat stress tolerance in wheat.

He outlined how he used his Mike Carroll Travelling Fellowship to visit the Plant Breeding Institute, Narrabri and The University of New England in New South Wales.

The final speaker was PhD candidate William Thomas from UWA's Batley Lab, who travelled to Canada to undertake research related to identifying new sources of disease resistance in canola.

William Thomas, Professor Jacqui Batley, Professor Kadambot Siddique, Mukesh Choudhary, Coco Divola, Marie-Louise Carroll, Helen Carroll, Michael Young and Professor Phil Vercoe.

The global challenge of food production & role of new technologies

Will we one day be growing wheat in 10-layer indoor vertical farms?

While it may seem far-fetched, Professor of Digital Agriculture Senthold Asseng has shown that wheat grown in indoor vertical structures under optimised growing conditions can result in several hundred times higher yields than in the field.

It could also lead to several harvests per year, use less land, be independent of climate, reuse most water, exclude pests and diseases, and have no nutrient losses to the environment.

Professor Asseng, who is the Director of the World Agricultural Systems Center at the Technical University of Munich in Germany, delivered a special public lecture for IOA in March.

"It is clear that the world needs to produce more healthy food with less environmental impact, whilst overcoming the challenges of climate change," he told the 120-strong audience.

As food demand continues to increase alongside a growing global population, Dr Asseng emphasised that environmental degradation, high water use, pesticide applications, nutrient pollution and biodiversity loss had rendered many current cropping systems unsustainable.

His lecture explored how automation and controlled-environment food production offered massive productivity gains with reduced environmental impact.

Professor Senthold Asseng delivering his lecture at UWA.

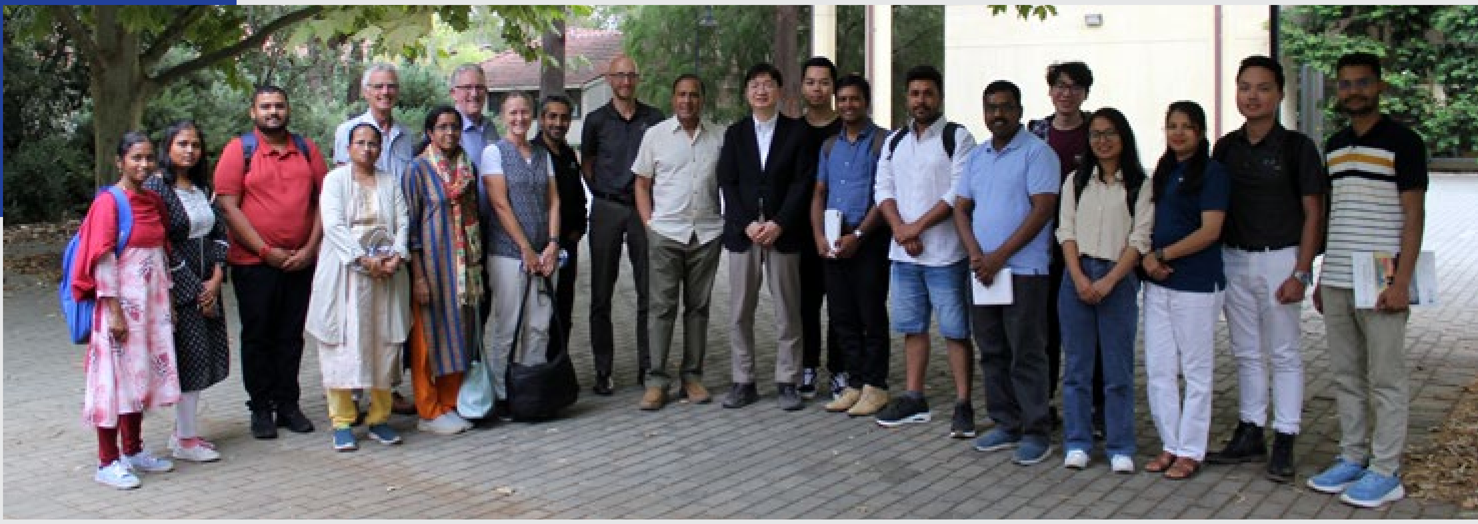
Introduction to multidisciplinary vegetable crop research

IOA warmly welcomed Yamaguchi University plant geneticist Professor Masayoshi Shigyo to UWA's Crawley campus in early March.

Hackett Professor Kadambot Siddique, UWA Deputy Vice Chancellor (Research) Professor Anna Nowak, Honorary Research Fellow Peter Batt and Professor Shigyo discussed potential avenues for research exchange between their two universities.

Professor Shigyo then delivered a public lecture on his multidisciplinary vegetable crop research to about 40 people at the UWA Agriculture Lecture Theatre.

Having engaged in genetic and breeding research for more than three decades, he recently turned his attention to searching for vegetable genetics resources in various parts of Asia.



A group of attendees following Professor Masayoshi Shigyo's lecture.

Can we reduce dependence on herbicides for cropping?

Professor Steve Shirtliffe and Professor Ken Flower outside the lecture theatre.

Is Western Australia the 'Disneyland of herbicide resistance'?

While it's unlikely to appear as a new tourism slogan, Professor Steve Shirtliffe said WA had earned this title as it was home to 'almost every resistance possible' during his recent lecture for the Australian Herbicide Resistance Initiative (AHRI).

The lecture, co-hosted by IOA, explored how we can reduce dependence on herbicides for cropping from a Canadian perspective.

"Broadacre cropping relies heavily on herbicides for weed control because they are highly effective and can be applied rapidly over large areas," he said.

"However, there are increasing challenges, such as herbicide resistance, and a need to use agro-chemicals more effectively to reduce their use."

Although he is also applying new technologies to agronomy – such as unmanned aerial vehicles and drones – Professor Shirtliffe suggested that the humble rotary hoe offered a novel weed control solution.

Professor Varghese Manaloor (third from left), Hackett Professor Kadambot Siddique, members of the UWA Global Engagement Office, and Dr Amin Mugera.

China's demand for food-away-from-home

With urbanisation and higher disposable income, demand for food-away-from-home in China has greatly increased, according to University of Alberta Professor Varghese Manaloor.

Professor Manaloor, who is the John P. Tandberg Chair in Economics, delivered a special lecture for the IOA in early 2023.

His talk referenced yet-to-be-published research he conducted in collaboration with student Ruotong Zhang and research intern Youhan Lu.

Professor Manaloor said China's economy had grown significantly over the past four decades, with per capita booming since liberalisation.

The most significant change regarding household consumption patterns in the post-reform period, he explained, was an increase in the demand of food-away from home in restaurants and eateries.

UWA Lefroy Fellow 2023 Research Seminar

Issues in livestock reproduction parallel and even foreshadow emerging issues in human reproductive health – making livestock systems incredibly valuable populations to study fertility, according to Lefroy Research Fellow Dr Kelsey Pool.

Reproductive biologist Dr Pool explored what she called the 'silent pandemic' of mammalian infertility during her Lefroy Fellow 2023 Seminar in May.

"For the past three years, the COVID-19 pandemic has dominated the media," she said.

"Far less talked about however, is another pandemic spanning decades – an insidious increase, globally, in mammalian infertility."

Through her work to improve sheep reproduction, she has uncovered how dietary endocrine disruptors contribute to male fertility.

"In an agricultural context, this also addresses an 80-year-old myth that oestrogenic pastures, high in 'plant oestrogens' or phytoestrogens are safe for working rams," Dr Pool said.

"They are not, and in fact contribute to reduced reproductive function in the ram."

In addition, by treating twin-bearing ewes with a neurohormone called melatonin during late gestation, Dr Pool said it was possible to provide these twin offspring with a physiological advantage before they were born.

"This study offers a commercial solution to improve twin lamb welfare and productivity, whilst also providing insight into strategies to mitigate fetal hypoxia and trauma common in twin pregnancies in several mammalian species," she said.

Dr Pool's seminar also included her research into using markers of fertility as a bioassay for biological de-fleecing.

Her team have identified potential alternatives to current methods of biological defleecing, which will allow sheep producers an alternative to manual shearing once refined and tested.

> "In an agricultural context, this also addresses an 80-year-old myth that oestrogenic pastures, high in 'plant oestrogens' or phytoestrogens are safe for working rams."
> **Dr Kelsey Pool**

Dr Kelsey Pool outside the UWA Bayliss Lecture Theatre.

Postgraduate Showcase: Frontiers in Agriculture

Delivering the opening address at IOA's 17th annual Postgraduate Showcase was the perfect full-circle moment for DPIRD Chief Scientist Dr Ben Biddulph.

Dr Biddulph attended the event 15 years previously – not as an audience member – but as a student presenter himself.

To date, 129 early-career researchers have presented their achievements in agriculture and related areas at the Postgraduate Showcase.

In addition to Dr Biddulph, notable former presenters include the UWA Centre for Agricultural Economics and Development Deputy Director Dr Fiona Dempster, West Midlands Group executive officer Dr Nathan Craig, and InterGrain Business and Research Development Manager Dr Dini Ganesalingam.

In his speech to the 100-strong audience, Dr Biddulph said he was enthusiastic about hearing from the next generation of agricultural researchers.

Seven outstanding postgraduate students from across three schools were hand-picked to present their research achievements, and each were coached by Emeritus Professor Graeme Martin.

The two sessions were chaired by the Head of the UWA School of Agriculture and Environment Associate Professor Matthias Leopold and UWA Business School Professor Sharon Purchase.

The innovative topics included Marcela Del Carmen Vieira tracing the economic impact of dung beetles in Australia, Junrey Amas identifying disease resistance in canola, and Mukesh Choudhary and Samalka Wijeweera investigating how to enhance heat stress and salt (respectively) tolerance in wheat.

Sylvester Obeng-Darko expanded on the factors that influence dihydroxyacetone in honey, Bablu Hira Mandal explored the role of fulvic acid in alleviating glyphosate damage to crops, and Doraid Alkhishaybi shared his research findings on the effect of heat stress on the sperm quality in Merino rams.

Dr Ben Biddulph presenting the welcome address.

Student presenters Junrey Amas, Marcela Del Carmen Vieira, Bablu Hira Mandal, Sylvester A Obeng-Darko, Samalka Wijeweera, Doraid Alkhishaybi and Mukesh Choudhary.

Importance of microbial resources for UN Sustainable Development Goals

Microbiology is one of the most important disciplines feeding into the United Nations' Sustainable Development Goals, according to Associate Professor İpek Kurtböke from the University of the Sunshine Coast.

During her special lecture hosted by IOA in July, Associate Professor Kurtböke explained that the preservation of microbiological cultures had far-reaching scientific, industrial, agricultural, environmental, and medical purposes.

"There are microbial bioindicators that are telling us, all the time, about the dangers and effects of pollution, climate change and global warming," she said.

Associate Professor Kurtböke emphasised the importance of microbial culture collections and their sustainable use for biotechnology.

More than 3,000 food grade strains are integrated into the Nestlé network, which helps them develop and produce a large range of functional foods containing beneficial microbes.

Associate Professor İpek Kurtböke with Associate Director Professor Cowling outside the UWA Agriculture Lecture Theatre.

Phenotyping of rice for high temperature and CO_2 environment

The growth and productivity of agricultural crops are impacted by global climate change mediating rising atmospheric carbon dioxide (CO_2) and air temperature, says IOA Adjunct Professor Madan Pal Singh.

Professor Singh, an Emeritus Scientist (Plant Physiology) at the Indian Council of Agricultural Research (ICAR) within Indian Agricultural Research Institute (IARI), explored his research into phenotyping of rice for high temperature and CO_2 environment at UWA lecture in September.

He told the audience that high CO_2 had been expected to increase crop yields through increased photosynthesis, however, a concurrent rise in temperature could mitigate these beneficial effects.

To phenotype rice accessions for spikelet fertility, grain yield, membrane stability, and chlorophyll fluorescence, Professor Singh and his research team exposed a diverse set of rice accessions to high temperature stress (HT) at the flowering stage.

He also outlined the results of a second study, which demonstrated that the effect of CO_2 on rice crop development and yield may be offset by a concomitant rise in air temperature.

Professor Madan Pal Singh delivering his lecture.

IAB member Belinda Eastough facilitating the panel discussion.

Industry Forum

Paving the way for the future of WA agriculture

After three to six generations of selective breeding (and some interbreeding), Western Australian farmers are like resistant weeds, WAFarmers chief executive Trevor Whittington declared in his keynote speech at IOA's 2023 Industry Forum.

"They are good at survival, so there'll always be another generation of WA farmers," Mr Whittington said.

"Rather, my focus will be on the question: What do we need to do to put the whole agricultural ecosystem in WA on the global map?"

This question and many more were explored at the 17th annual Industry Forum, supported by CSBP and Farmers Ltd Golden Jubilee of Agriculture Science Fellowship and held at the University Club of WA on 19 July.

More than 230 guests, including agriculture industry leaders and analysts, researchers and working farmers attended the event, which was focused on the next generation of WA agriculture.

It was opened by the Hon Jackie Jarvis MLC, marking her first official visit to UWA since her appointment as Minister for Agriculture and Food; Forestry; Small Business.

IOA's Industry Advisory Board (IAB) members InterGrain Chief Executive Officer Tresslyn Walmsley and Belinda Eastough served as Master of Ceremonies and panel discussion facilitator, respectively.

For her presentation, farmer and UWA Centre for Agricultural Economics & Development Deputy Director Dr Fiona Dempster said her greatest advice to young researchers was to "Be curious and keep coming back".

Agricultural Education Director Sally Panizza outlined the Department of Education's strategic plan to provide every agricultural college student a pathway to a successful future.

Georgia Pugh explored innovative new ag tech from her unique perspective as a neXtgen Agri consultant helping farmers adopt and navigate the sector.

Trevor Whittington presenting the keynote.

CBH Group chief executive Ben Macnamara reminded the audience that there were "no quick wins in agriculture".

Agronomist, project manager and RnD coordinator Nick Eyres concluded the afternoon on a philosophical note.

"The single biggest contribution we can have to our industry is the continual inspiration of passion within the next generation, and making sure the doors of infinite impossibilities remain open at all times," Mr Eyres said.

Cracking the genetic code of super weeds

Who controls the 'dimmer switch' when it comes to multiple herbicide resistance through enhanced metabolism?

Assistant Professor Satoshi Iwakami tackled this challenging question and more while delivering a seminar for IOA and AHRI in September.

Dr Iwakami, who specialises in molecular weed science at Kyoto University's School of Agriculture, completed his post-doc at Bayer Crop Science in Germany.

His seminar, titled 'Cracking the genetic code of super weeds: How a paddy weed defeats selective herbicides in rice' was attended by more than 40 people.

Dr Iwakami's research team studied a rice paddy weed *called Echinochloa phyllopogon* to better understand the mechanism behind this broad-spectrum herbicide resistance.

They found that the resistance was caused by multiple P450s working together to detoxify many different kinds of herbicides.

It was a busy visit to Perth for Dr Iwakami, who also attended the Weeds Genomics Workshop (organised by Colorado State University Dr Todd Gaines, who was on sabbatical at AHRI) following the International Plant and Animal Genome Conference.

Kyoto University Assistant Professor Satoshi Iwakami.

Manoj Kumar Menon presenting at the UWA Agriculture Lecture Theatre.

The umbrella of sustainable agriculture: Agroecology, organic & natural farming

Sustainable agriculture could be seen as a 'time machine' for us to travel back and correct our wrong turns, says Executive Director of the International Competence Centre for Organic Agriculture (ICCOA) Manoj Kumar Menon.

In October, Mr Menon delivered a special lecture for IOA titled 'The Umbrella of sustainable agriculture: Agroecology, organic & natural farming'.

The United Nations' Food and Agriculture Organization defines sustainable agriculture as meeting the needs of present and future generations, while ensuring profitability, environmental health, and social and economic equity.

"Whatever we can do to make sure that the present and the future both are taken care of is sustainable," Mr Menon said.

During the lecture, a video introduced the audience to the Jaivik Vigyan Kendra Centre for Sustainable and Organic Farming, run by ICCOA, which functions as a model organic farm and training centre near Bangalore, India.

UWA Farm Ridgefield 2023 Open Day

The sun was shining and spirits were high on Friday 6 October when IOA welcomed more than 150 researchers, working farmers, members of the local community and beyond to its UWA Farm Ridgefield 2023 Open Day.

Photos (clockwise from left):

UWA Vice Chancellor Amit Chakma presenting his speech to the crowd of more than 150 people.

The Hon Mia Davies MLA and Hackett Professor Kadambot Siddique chat at the start of the Open Day.

Critical Zone Observatory Technical Field Officer Allan Williams presenting on the Vadose-zone Monitoring System.

Members of the Pingelly Tourism Group showing off some of the homemade sandwiches on offer for lunch.

Hackett Professor Siddique, Professor Chakma, Farm Manager Tim Watts, Emerita Professor Lynette Abbott and IOA Business Manager Diana Boykett.

The Open Day featured in-field visits and project demonstrations that showcased key UWA research related to the Best Practice Farming Systems Project.

Institute Director Hackett Professor Kadambot Siddique delivered the introductory speech at the Old Farmhouse, during which he provided a background on how the 1600 ha mixed-enterprise farm has supported agricultural research at UWA since 2009.

In his speech, Pingelly Shire President Bill Mulroney shared his personal recollections of UWA Farm Ridgefield and emphasised the important relationship between UWA and the Pingelly community.

UWA Vice Chancellor Professor Amit Chakma then introduced The Nationals WA Member for Central Wheatbelt The Hon Mia Davies MLA to formally open to event.

Following lunch catered by the Pingelly Tourism Group, attendees boarded buses to visit the seven research demonstration sites across the farm.

First on many enthusiastic visitors' agenda was UWA Emerita Professor Lynette Abbott's recently established trial FutureCarbon13 Project 2023-2028, titled 'Grazing into the future for soil carbon sequestration and building soil health'.

A few minutes' bus ride away, Murdoch University Associate Professor Rachel Standish presented on the long-term Multiple Ecosystems Services Experiment.

UWA Associate Professor Louise Barton and Paul Damon led people around one of four WA field trials as part of the national 'Predicting nitrogen cycling and losses in Australian cropping systems' project.

Twelve field trials commenced in 2023 across Australia (four in WA conducted by UWA) in partnership with the Department of Primary Industries and Regional Development.

At Avery's Shearing Shed, UWA Lefroy Fellow Dr Kelsey Pool and Associate Professor Dominique Blache took turns presenting on their projects; 'Redefining ovine clover disease: A role for rams?' and 'Research into heat stress in livestock', respectively.

Crowds formed around UWA Associate Professor Sally Thompson and her research team to learn more about The Avon Critical Zone Observatory (CZO) – Western Node of the Australian CZO Network.

Rounding out the site visits was Associate Professor Phillip Nichols and Brad Wintle, who demonstrated the latest findings from their Annual Legume Breeding Australia (ALBA) field trials.

Many passionate and hardworking people helped make the UWA Farm Ridgefield 2023 Open Day such a success – Farm Manager Tim Watts, research leaders and their teams, IOA staff, student volunteers, members of the Pingelly community, and more.

The Open Day featured in-field visits and project demonstrations that showcased key UWA research related to the Best Practice Farming Systems Project.

Professor Paul Kenyon presenting at the UWA Agriculture Lecture Theatre.

Alan Sevier Memorial Lecture

Sheep production systems in New Zealand have adapted and evolved over the past 30 years to match the drivers of on-farm income.

While delivering the 2023 Alan Sevier Memorial Lecture in September, Massey University Professor Paul Kenyan explored how research coupled with technology transfer and farmer interaction influenced this evolution.

Professor Kenyon said lamb production drove farmer decision making.

“Research coupled with technology transfer and farmer interaction has driven the increases observed in ewe reproductive rate, lamb growth rates and carcass weights at slaughter,” he said.

“While the national flock is significantly less than half of its 1980s size, total industry carcass weight has only dropped by 14 per cent.”

Professor Kenyon explained that the sheep industry in New Zealand was traditionally driven by course wool (above 30 micron) production.

“However, with the relative and absolute value of wool falling, coupled with increased shearing costs, farmers have needed to adapt to ensure they remain economically viable,” he said.

The lecture was attended by animal scientists and farmers, including UWA Farm Ridgefield Farm Manager Dr Tim Watts.

It also explored ewe lamb breeding, management to maximise multiple bearing ewe performance, targeted feeding to maximise return, alternative herbages, and efficiency drivers of the New Zealand system.

Leveraging smallholder farmers in a changing agricultural scenario

Smallholder farms account for 96 per cent of agriculture in all of Kerala, India – 10 per cent higher than the national rate.

In November, Kerala Agricultural University Professor Jayasree Krishnankutty delivered a special lecture for IOA titled 'Leveraging smallholder farmers in a changing agricultural scenario – Perspectives from Kerala'.

Professor Krishnankutty said Kerala stood out from the rest of the Indian states in having the highest Sustainable Development index, highest density of population, and its people moving more towards the service sector.

"Kerala can be a case study in how a fast-urbanising state can also support and promote agricultural sustainability," she said.

With smallholder agriculture in Kerala currently under transition, Professor Krishnankutty said small emerging farmers were making a positive impact.

Professor Krishnankutty was the principal investigator (India side) of the ARC Discovery Project between UWA and Kerala Agricultural University on food security and the governance of local knowledge.

ARC Discovery Project research collaborators Institute Director Hackett Professor Kadambot Siddique, Professor Jayasree Krishnankutty and Professor Michael Blakeney outside the lecture theatre.

Harnessing genomics to improve weed management

A herbicide resistance epidemic of the grass weed known as blackgrass (*Alopecurus myosuroides*) is sweeping through the UK.

At his seminar hosted by AHRI with support from IOA in December, visiting academic Professor Paul Neve from the University of Copenhagen presented results from a large, multi-year and multidisciplinary project that sought to unravel the molecular mechanisms and ecological, evolutionary and agronomic drivers of this epidemic.

Operating from 'field to gene', the project established a large farm network (70 farms) in the UK across which blackgrass populations were mapped, seed populations were collected, and resistance was characterised at whole plant and molecular levels.

Uniquely, the project also collected extensive, historical field management records to explore drivers of resistance evolution.

The seminar demonstrated the value of field epidemiological approaches for dissecting the effects of field and farm management practices on the risks, abundance, and mechanisms of resistance to multiple herbicide modes of action in blackgrass.

Professor Paul Neve spent six years in the 2010s as a postdoctoral researcher at AHRI.

Hector and Andrew Stewart Memorial Lecture

If worldwide food production increased 129 per cent from 1970 to 2010, then surely our current goal to increase 60 per cent by 2050 will be a piece of cake?

This could not be further from the truth, according to University of Queensland Adjunct Professor John Dixon, who delivered the 29th Hector and Andrew Stewart Memorial Lecture in November.

"We are losing land to degradation and urbanisation, temperatures are rising with climate change, precipitation is shifting, the amount of fresh water available for irrigation will reduce, and there are mounting geopolitical pressures," Adjunct Professor Dixon said.

"It is no wonder that progress towards the United Nations' 17 Sustainable Development Goals set off at a slow pace from 2015 and ground to a halt during the pandemic."

Adjunct Professor Dixon argued that it would require more science, more effective implementation, and more collaboration across disciplines, agencies, governments, and regions than in the past to achieve the 2050 goal.

"It will be my contention this evening that we have failed our jobs in terms of incorporating sustainability and resilience into our agricultural development and food development systems globally," he said.

In closing, Adjunct Professor Dixon said Sustainable Intensification was required to increase food production from existing land and water resources while minimising pressure on the environment.

This lecture series is held in honour of the late Hon Hector J Stewart, MLC and his son, the late Mr Andrew M Stewart, both Wagin wool growers.

Mr Stewart Jr was President of UWA's Guild of Under- graduates in 1929 and twice Dean of UWA's Faculty of Agriculture.

Adjunct Professor John Dixon presenting at the UWA Bayliss Lecture Theatre.

Members of the Stewart family and special guests. This lecture is held in honour of the late Hon Hector J Stewart MLC and his son Andrew Stewart.

Garima with Catalina Farms owner and IOA IAB member Rod Birch.

GRDC Grains Research Update

The newly launched Farm to Port Project was front-and-centre of IOA's information stall at the Grains Research and Development Corporation (GRDC) Grains Research Update in February.

With guidance from her supervisors Hackett Professor Kadambot Siddique and Associate Professor Doina Olaru, UWA PhD candidate Garima is leading the project to develop an optimisation model to improve the agri-food supply chain and benefit growers across Australia.

The UWA-based AHRI was well-represented at the two-day Updates with multiple talks delivered by their researchers, including new Director Professor Ken Flower.

Associate Professor Louise Barton presented a 10-year perspective on her research into nitrous oxide emissions from cropping soils in the WA grainbelt, and Professor Ross Kingwell shared his thoughts on the grain export supply chain challenges.

On the second day, IOA Research Fellow Dr Sheng Chen delivered a talk on the progress he has made towards the discovery of genes for heat stress tolerance in a diverse canola population.

UWA students Hera Nyugen and Michael Young then explored their postgraduate research findings as part of the new researchers' snapshots segment.

Dowerin Field Days

There was great excitement and commotion when the UWA Students of Natural and Agricultural Science (SNAGS) group came to visit IOA's information stall at 2023 Dowerin Machinery Field Days in August.

The Institute sponsored the SNAGS' inaugural three-day Dowerin Camp – which included field trips, farm tours, field day demonstrations and networking.

SNAGS Social Vice President Kaitlin Williams said the 'hugely successful' event was made affordable for students with financial assistance from IOA.

"Attendees were given the opportunity to gain valuable knowledge and access to resources and industry connections that will help them during their university career at UWA and as graduates," Ms Williams said.

The information stall within the DPIRD shed was run by Guan Cheng and PhD candidates Ruby Wiese, Agyeya Pratap, Garima and Emanuel Gomez, who informed visitors about their research projects and encouraged them to participate in related surveys.

The UWA SNAGS group visiting the IOA info stall at Dowerin Field Days.

Best Practice Farming Systems (BPFS) Project: 2023 Highlights

Previously known as the Future Farm 2050 Project, the Best Practice Farming Systems (BPFS) Project at UWA Farm Ridgefield facilitates multidisciplinary research and innovation to deliver robust farming systems that are economically viable, environmentally credible and create tangible social benefits. The BPFS Project is guided by the following strategic priorities.

Mitigation of on-farm greenhouse gas emissions: Substantially reduce greenhouse gas emissions from ruminant livestock, cropping activities and promote widespread adoption of renewable energy in regional WA.

Adaptations for the changing climate: Implement climate adaptation innovations that protect the viability of livestock and cropping enterprises.

Profitable, ethical production systems: Profitable dryland farming systems that deliver clean, green and ethical products and outcomes that meet consumer and community expectations and underpin our social license.

Restoration of ecosystems and biodiversity: At landscape scale, use native plant species to restore biodiversity and soil functions to provide ecosystem services such as water availability, carbon capture and erosion prevention.

Education, community engagement and capacity building: Build partnerships with regional communities in targeted educational initiatives, capacity-building and outreach projects with triple bottom line outcomes and societal benefits.

Outreach

The highlight of the year was the UWA Farm Ridgefield 2023 Open Day held on 6 October, which was attended by approximately 150 researchers, staff, students, local community, farmers, industry partners, government and general public. It included on-site research demonstrations from Grazing into the future for soil carbon sequestration and building soil health; Annual Legume Breeding Australia (ALBA); Redefining ovine clover disease: a role for rams; Ridgefield Multiple Ecosystems Services Experiment Merino Lifetime Productivity (MLP) Project; Research into heat stress in livestock; The Avon Critical Zone Observatory - Western Node of the Australian CZO Network; Managing Merino weaners to survive and thrive; and Predicting nitrogen cycling and losses in Australian cropping systems.

In 2023, the BPFS Project's strong online presence enabled engagement with people all around the world. A total of 2,581 people were following the BPFS Project page on Facebook by the end of the year.

Throughout 2023, eight newsletter articles and three media releases were published. The prestigious Uniview magazine Winter edition focused on agriculture and food production. It included two articles on UWA Farm Ridgefield and related BPFS Project research. UWA's Research on the Record also released a podcast featuring Dr Kelsey Pool talking about the challenges of dividing her time between farm and lab for her hands-on research.

The Massive Open Online Course Discover Best Practice Farming for a Sustainable 2050 attracted a further 3000 enrolments in 2023, reaching a total of more than 40,000 since it was launched in 2017. This free course provides an overview of major issues in sustainable agriculture and illustrates them with the four key enterprises of the BPFS Project: livestock, cropping, sustainability and a vibrant community.

Dr Pool delivered the Lefroy Fellow 2023 Research Seminar in May 2023 at Bayliss Lecture Theatre, featuring her research at UWA Farm Ridgefield. The IOA information stall at the 2023 Dowerin Field Days in late August featured information on UWA Farm Ridgefield, BPFS Project through flyers, posters and engagement with attendees.

UWA Farm Ridgefield also attracted many international visitors in 2023. Three academics from the University of New Hampshire, USA visited the farm on 30 June, accompanied by Dr Kevin Foster. The following month, 20 undergraduate students from Huazhong Agricultural University, China visited on 19 July. Five researchers from Acharya N. G. Ranga Agricultural University visited UWA Farm Ridgefield and received presentations on livestock research from Associate Professor Dominique Blache and Dr Pool. Finally, a delegation of livestock research scientists from Food & Agricultural Research & Extension Institute in Mauritius visited UWA Farm Ridgefield on 23 September, accompanied by Emeritus Professor Martin.

Research and training
Education

On-farm education is integral to the BPFS Project, and UWA Farm Ridgefield provides an excellent platform for practical field experience.

Throughout the year, more than 150 UWA students attended study excursions to Ridgefield or visited for research purposes including students from the AGRI2201 Pasture and Livestock Systems unit, the SCIE5507 Food Fibre and Fuel Security unit, and the ANIM3306 Clean Green and Ethical Animal Production unit.

Nine Master's and PhD students completed work at UWA Farm Ridgefield as part of their studies ranging from livestock production to soil productivity and carbon sequestration.

Seventeen active research projects conducted on UWA Farm Ridgefield started or continued during 2023, resulting in at least four peer-reviewed journal publications. CSIRO's Dr Hayley Norman led the project 'Edible Shelter developed for implementation at Ridgefield', and two Murdoch University led 'Managing Merino weaners to survive and thrive' and 'The Impact of crop height on survival of twin-born lambs' were carried out on Ridgefield. Meat and Livestock Australia sponsored research on heat stress in livestock, and the GRDC on 'Predicting nitrogen cycling and losses in Australian cropping systems'.

The Annual Legume Breeding Australia (ALBA) – stage 2 sub clover variety trial also took place this year, in partnership with DLF Seeds. DPIRD supported the project 'Grazing into the future for soil carbon sequestration and building soil health', and Associate Professor Blache enhanced collaboration with Western Australian Livestock Research Council, as the UWA-WALRC representative. The Department of Industry, Science and Resources provided funding for the 'MERiL2: Agolin as AM Additive' project led by Dr Zoey Durmic.

The BPFS Project continued its partnership the national Animal Welfare Collaborative, Australian Association of Animal Science, and Pingelly Community Resource Centre. It is a member of the Worldwide Universities Network's Global Farm Platform (which includes 23 Institute members and 15 farm platforms across all continents), the Critical Zone Exploration Network, and the Terrestrial Ecosystems Research Network.

Photos (previous page):

(Left) Master's student Dan Kierath conducting soil sampling at UWA Farm Ridgefield.

Ang Sing monitoring sheep wellbeing at the farm as part of the MERiL project

Photos (clockwise from left):

A group of Open Day attendees pose for a photo in the field near Associate Professor Louise Barton's research site.

Lefroy Fellow Dr Kelsey Pool during tagging activities for the Shade and Shelter Project.

Professor Shane Maloney after a long, dusty day at UWA Farm Ridgefield.

Huazhong Agricultural University visitors at the entrance to the farm.

Media statements

IOA communicated its research outcomes to the public through the media by distributing 30 media statements in agriculture and related areas in 2023. A commendable amount of media coverage was generated in local, rural, national and international print, broadcast and online media.

Date	Title
17 January	Agricultural economics expert awarded prestigious US Fellowship
18 January	Table grape industry ripe for growth in Northern Australia
19 January	Innovative crop breeding method to meet future global demand for grains
23 January	Professor Ken Flower digs in to AHRI Director role
2 February	Can plants be genetically programmed to save themselves?
3 February	Proven method to reduce fertilisation and increase economic and environmental benefits
2 March	UWA launches second phase of research to reinvent the wheat pre-breeding model
15 March	Young Professionals in Agriculture Forum champions graduates' research
29 March	Breaking new ground with water monitoring tech at UWA Farm Ridgefield
30 March	Accelerated breeding at UWA used for genetic gain in chickpeas
19 April	The UWA Institute of Agriculture Director awarded highest honour
20 June	Hub extension and adoption bursaries awarded to UWA students
4 July	UWA plant scientist awarded Australian Laureate Fellowship
10 July	UWA appoints Chair in Plant Physiology
20 July	Top researchers recognised as finalists in Premier's Science Awards
28 July	Graduate to head new agricultural research collaboration
14 August	Living with the land Agricultural science focus for Uniview Winter 2023 edition
7 September	New Centre for Water and Spatial Science opens at UWA
11 September	Scientists pinpoint positive feedback loop of carbon sequestration
12 September	Hackett Professor Kadambot Siddique named Scientist of the Year
12 September	UWA researchers recognised in Premier's Science Awards
20 September	The UWA Institute of Agriculture releases 2022 Annual Research Report
26 October	Unique canola research aims to beat the heat
7 November	Hackett Professor Siddique to join Fellowship of the World Academy of Sciences
15 November	13 academics named highly cited researchers for 2023
15 November	Offshore wind turbines and legume research boosted by grants
17 November	Scientists come together to explore the Critical Zone
20 November	BeefLinks: Steaks are high for future of WA beef
1 December	How going against the grain forged an industry-leading career
12 December	National funding boost for net-zero agricultural alliance

Awards and industry recognition

Name	Award
H/Prof Kadambot Siddique	Sanqin Friendship Award, Shaanxi Provincial Government
Dr Terry Enright	GRDC Seed of Gold award
Ruby Wiese	AW Howard Research Fellowship
James O'Connor	AW Howard Memorial Trust Tim Healey Scholarship
Alistair Hockey	AW Howard Memorial Trust Tim Healey Scholarship
George Mercer	AW Howard Memorial Trust Tim Healey Scholarship
H/Prof Kadambot Siddique	Top 100 Best Plant Science and Agronomy Scientist – *Research.com*
E/Prof Hans Lambers	Top 100 Best Plant Science and Agronomy Scientist – *Research.com*
Prof Nanthi Bolan	Top 100 Best Plant Science and Agronomy Scientist – *Research.com*
Ad/Prof Neil Turner	Top 100 Best Plant Science and Agronomy Scientist – *Research.com*
E/Prof Rana Munns	Top 100 Best Plant Science and Agronomy Scientist – *Research.com*
H/Prof Kadambot Siddique	Wiley Top Cited Article 2021-2022
Prof Nanthi Bolan	Wiley Top Cited Article 2021-2022
A/Prof Parwinder Kaur	WA Women's Hall of Fame - STEM
Adj/Prof Ashwani Pareek	Fellowship for the Indian National Science Academy, India
Adj/Prof Ashwani Pareek	R N Tandon Memorial Lecture award from the National Academy of Sciences, India
Elliott Fourie	Westpac Future Leaders Scholarship
Georgia Welsh	Noel Fitzpatrick Medal – Young Professionals in Agriculture Forum
Dan Kierath	2023 WA Livestock Research Council scholarship
Garima	South-West WA Drought Resilience Adoption and Innovation Hub bursary
Jane Brownlee	South-West WA Drought Resilience Adoption and Innovation Hub bursary
Emanuel Gomez	South-West WA Drought Resilience Adoption and Innovation Hub bursary
Dan Kierath	South-West WA Drought Resilience Adoption and Innovation Hub bursary
H/Prof Kadambot Siddique	2023 Scientist of the Year – WA Premier's Science Awards
Prof David Pannell	2023 Fellow of the Agricultural and Applied Economics Association
Prof Jacqueline Batley	2023 Australian Laureate Fellowship
Dr Kelsey Pool	FameLab Australia 2023 Finalist
Sneha Papula Reddy	Best Poster Award – ICRISAT International Conference on Innovations to Transform Drylands
H/Prof Kadambot Siddique	Fellow of The World Academy of Sciences
H/Prof Kadambot Siddique	The Australian's 2023 Research Magazine 'Top Researcher' in Agronomy & Crop Science
Prof Sergey Shabala	The Australian's 2023 Research Magazine 'Top Researcher' in Botany
H/Prof Kadambot Siddique	2023 Clarivate Highly Cited Researcher (Agricultural Sciences and Plant & Animal Science)
Prof Jacqueline Batley	2023 Clarivate Highly Cited Researcher (Plant & Animal Science)
Prof David Edwards	2023 Clarivate Highly Cited Researcher (Plant & Animal Science)
E/Prof Hans Lambers	2023 Clarivate Highly Cited Researcher (Plant & Animal Science)
Prof Sergey Shabala	2023 Clarivate Highly Cited Researcher (Plant & Animal Science)
Prof Zed Rengel	2023 Clarivate Highly Cited Researcher (Cross-Field)
E/Prof Graeme Martin	Society for Reproductive Biology Life Membership
Sneha Priya Pappula Reddy	Australian Society of Plant Scientists Student Travel Award
Michael Young	UWA Department of Agricultural and Resource Economics' Award for Best PhD Thesis

New PhD research students

Name	Topic	School	Supervisor(s)	Funding body
Linda Lindongi	The role of arbuscular mycorrhizal fungi in soil amended by organic waste resources	UWA School of Agriculture and Environment	Dr Sasha Jenkins E/Prof Lynette Abbott	Australian Award Scholarship
Elliott Fourie	RNA-targeting CRISPR systems for gene regulation in plants	UWA School of Agriculture and Environment	Prof Ryan Lister Prof Ian Small Dr Adil Khan	Westpac Future Leaders Scholarship Jean Rogerson Postgraduate Scholarship
Huyen Pham	Water and phosphorus efficiency in wheat	UWA School of Agriculture and Environment	H/Prof Kadambot Siddique Dr Jairo Palta Dr Jiayin Pang	Ministry of Education and Training, Vietnam Int. Cooperation Dept
Chuangwei Fang	Phosphorus use efficiency in chickpea	UWA School of Agriculture and Environment	E/Prof Hans Lambers H /Prof Kadambot Siddique Dr Jiayin Pang	ARC Linkage Project
Xiaolong Feng	Phosphorus remobilisation in chickpea	School of Biological Sciences	E/Prof Hans Lambers H /Prof Kadambot Siddique Prof Megan Ryan A/Prof Peta Clode Dr Jiayin Pang	ARC Linkage Project
Huaikang Jing	Seed phosphorus in chickpea	School of Biological Sciences	E/Prof Hans Lambers H/Prof Kadambot Siddique Prof Megan Ryan A/Prof Peta Clode Dr Jiayin Pang	ARC Linkage Project
Md Hosenuzzaman	Alleviating glyphosate damage to crops with fulvic acid and manganese	UWA School of Agriculture and Environment	Dr Sasha Jenkins E/Prof Lynette Abbott	Australian Award Scholarship
Noor Ahmed Shaik	The function of light spectrum in climate plasticity of grapevine	UWA School of Agriculture and Environment	A/Prof Michael Considine H/Prof Kadambot Siddique	UWA-CSC Innovating the Growth of Tropical Table Grapes Scholarship for International Research Fees
Oshadi Hettithanthrige Dona	Novel humate-based calcium formulations to ameliorate subsoil acidity	UWA School of Agriculture and Environment	Prof Nanthi Bolan H/Prof Kadambot Siddique Dr Zakaria Solaiman	UWA Omnia Specialties Ltd
Manika Rani Debnath	Engineered clay-polysaccharide nanocomposites for efficient nutrient delivery	UWA School of Agriculture and Environment	Prof Nanthi Bolan H/Prof Kadambot Siddique Dr Zakaria Solaiman	UWA-ARC Linkage Project
Yadav Padhyoti	Inefficiencies in Australian agricultural markets, marketing channel choice and acceptance of online commodity trading platforms	UWA School of Agriculture and Environment	Prof Marit Kragt A/Prof Amin Mugera A/Prof Ben White	Scholarship for International Research Fees ARC TC for Behavioural Insights for Technology Adoption
Olubukola Akangbe	Thesis title to be confirmed	UWA School of Agriculture and Environment	Dr Sebastien Allard Dr Sasha Jenkins Dr Andrea Cipollina Dr Anna Kaksonen	UWA-CSIRO HDR Scholarship Scholarship for International Research Fees
Roberto Lujan Rocha	A novel approach for scalable weed prediction and mapping to enable integrated weed management in Western Australian cropping systems	UWA School of Agriculture and Environment	Prof Ken Flower Dr Michael Ashworth Dr Catherine Borger A/Prof Nik Callow Dr Jonathan Richetti	RTP Fees Offset - Domestic Student

Memoranda of Understanding

Name	Date
Bac Lieu's Provincial Department of Planning and Investment	April 2023
Ha Nam Provincial Department of Education and Training	April 2023
Islamia University of Bahawalpur	June 2023
UWA and Sher-e-Kashmir University of Agricultural Sciences and Technology	November 2023
UWA and Rani Lakshmi Bai Central Agricultural University	November 2023
University of Ghana (renewal)	December 2023

New research grants

Title	Funding period	Funding body	Investigators
Differential solidification of steel slag to create a fertiliser co-product	2023-2026	ARC Linkage Project	Prof Tom Honeyands Prof Nanthi Bolan
Accelerated integration of physiology-based wheat traits within a commercial breeding programme	2023-2026	GRDC	A/Prof Nic Taylor Prof Harvey Millar
Intensification of northern cattle production in WA enabled by feed products from irrigated cropping	2023-2026	CRC for Developing Northern Australia	Prof Phil Vercoe A/Prof Dominique Blache Prof Shane Maloney
Determining the impacts of grazing oestrogenic clovers on cattle fertility	2022-2025	DPIRD	Prof Phil Vercoe Dr Tim Watts Jessica Shilling Dr Kevin Foster A/Prof Dominique Blache
Building an advanced genomics platform for Australian horticulture	2022-2027	Horticulture Innovation Australia Ltd Ex Murdoch	A/Prof Parwinder Kaur
Agricultural Innovations for Communities – Intensified and Diverse Farming Systems for Timor-Leste (AI-Com 2)	2022-2027	ACIAR	A/Prof Louise Barton E/Prof William Erskine A/Prof Matthias Leopold Prof Nanthi Bolan A/Prof James Fogarty A/Prof Fay Rola-Rubzen
Building new technologies for sustainable and profitable sub clover seed harvesting	2022-2025	AgriFutures Australia	A/Prof Andrew Guzzomi A/Prof Phillip Nichols Prof Megan Ryan Dr Wesley Moss Ruby Wiese Dr Joanne Wisdom
Between a hot place & hypoxia: Quantifying fish-kill risk in inland rivers	2023-2026	ARC Linkage Project	A/Prof Matthew Hipsey Dr Adrian Gleiss Prof David Hamilton Prof Craig Franklin Dr Jonathan Marshall Andrea Prior
Expanding phenological diversity in narrow-leafed lupin using novel flowering time genes (RFT)	2023-2025	GRDC	Prof Wallace Cowling
WAARC Key Personnel Funding	2023-2026	DPIRD	H/Prof Kadambot Siddique

Title	Funding period	Funding body	Investigators
Recharge in a changing climate	2023-2026	Department of Water and Environmental Regulation (WA)	Dr Sarah Bourke Dr Jim McCallum A/Prof Matthias Leopold A/Prof Sally Thompson
Effective control of blackleg of canola	2023-2028	GRDC	Prof Jacqueline Batley Prof Dave Edwards Dr Angela van de Wouw A/Prof Alexander Idnurm
Investigate genetic strategies to reduce virus spread through aphid vectors	2023-2027	GRDC	Prof Jacqueline Batley Prof Dave Edwards
Increasing intrinsic heat tolerance of wheat through improved genetics	2023-2026	GRDC	A/Prof Nic Taylor Prof Harvey Millar
The potential of biomineral fertilisers to increase soil carbon sequestration	2023-2025	Pedaga Investments	Dr Pete Hutton
National Soil Carbon Innovation Challenge – Development and Demonstration round 1	2023-2025	Department of Climate Change, Energy, the Environment and Water (Australia)	Dr Joanne Wisdom Prof Megan Ryan
Managing soil carbon to increase soil productivity	2023-2026	CRC Soils	Prof Nanthi Bolan
Unlocking new genetic systems for hybrid breeding in wheat	2023	UWA	Dr Joanna Melonek Prof Ian Small
UWA/DPIRD Joint Position in Agriculture	2024-2028	DPIRD	Prof Phil Vercoe
MERiL 2: Agolin as AM additive	2023-2025	Department of Industry, Science and Resources	Dr Zoey Durmic Stephanie Payne
A walk on the wild side: understanding disease resistance across plants	2023-2028	Australian Laureate Fellowship	Prof Jacqueline Batley
Investigating a novel genetic strategy for insect resistance in crops	2024-2029	ARC Discovery Projects	Prof Jacqueline Batley
Control of crop-microbe symbiosis by new plant hormones	2024-2029	ARC Discovery Projects	Dr Mark Waters Prof Megan Ryan Dr Philip Brewer A/Prof Caroline Gutjahr
Advancing plant synthetic gene circuit capability, robustness, and use	2024-2029	ARC Discovery Projects	Prof Ryan Lister Dr James Lloyd A/Prof Wayne Reeve Dr Julie Ardley
Accelerating pulse breeding using machine learning	2024-2027	ARC Linkage Projects (LP23 Round 1)	Prof David Edwards Prof Jacqueline Batley Dr David Tabah Dr Aanandini Ganesalingam
Zero Net Emissions from Agriculture Cooperative Research Centre	2024-2034	Cooperative Research Centre and Federal Government	Richard Heath Georgia Sheil Riaan Retief Michael Taylor Rachel Buchanan Annie Cox Prof Ben Hayes Vicki Lane Prof Philip Vercoe Prof Marit Kragt Prof Richard Eckard A/Prof Janelle Wilkes

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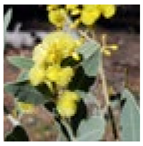

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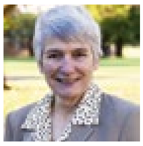

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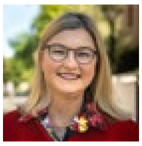
Institute Management Board (IMB)

The IMB brings together the heads of six UWA schools to provide high-level strategic direction and information exchange across agriculture and related areas at the university.



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Theme Leaders

The Theme Leaders co-ordinate research, development and related activities in their respective areas. The Theme Leaders Committee is chaired by Professor Phillip Vercoe and Professor Wallace Cowling.

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Industry Advisory Board (IAB)

The IAB provides IOA with industry interaction, advice and feedback. IAB members represent a cross-section of agricultural industries and natural-resource-management areas.

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Farmer

Rod Birch
Farmer

Dr Dawson Bradford
Farmer

Philip Gardiner
Farmer

Dr Bruce Mullan
Director Sheep Industry Development, Grains and Livestock Industries, DPIRD

Dr Hayley Norman
Senior Principal Research Scientist, CSIRO

Neil Young
Farmer

Hackett Professor Kadambot Siddique
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2023 Publications

Peer Reviewed Journals

1. Abbas G, Areej FA, Asad, SA, Muhammad S, Anwar-ul-Haq M, Afzal S, Murtaz B, Amjad M, Narem MA, Akram M, Akthar N, Aftab M and Siddique KHM (2023). Differential effect of heat stress on drought and salt tolerance potential of Quinoa genotypes: A physiological and biochemical investigation. *Plants* doi: 10.3390/plants12040774
2. Aggarwal SK, Hooda KS, Kaur H, Gogoi R, Chauhan P, Bagaria PK, Kumar P, Choudhary M, Tiwari RK and Lal MK (2023). Comparative evaluation of management modules against Maydis leaf blight disease in maize *Zea mays. European Journal of Plant Pathology* doi: 10.1007/s10658-023-02777
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4. Akbari S, Polyakov M and Iftekhar MS (2023). Capitalised nonmarket benefits of multifunctional water-sensitive urban infrastructure: A case of living streams. *Agricultural and Resource Economics* doi: 10.1111/1467-8489.12533
5. Akhoondzadeh H, Bouyeh M, Paz E, Seidavi A and Vlčková R (2023). The effect of dietary L-carnitine and fat on performance, carcass traits and blood components in broiler chickens. *Animal Science Papers and Reports* **41** 2 pp 111-122 doi: 10.2478/aspr-2023-0002
6. Al-Awad OAS, Prendergast KS, Robson A and Rengel Z (2023). Screening Canola Genotypes for Resistance to Ammonium Toxicity. *Agronomy-Basel* **13**(4) doi: 10.3390/agronomy13041150
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8. Amas J, Bayer P, Hong Tan W, Tirnaz S, Thomas W, Edwards D, and Batley J (2023). Comparative pangenome analyses provide insights into the evolution of *Brassica rapa* resistance gene analogs (RGAs). *Plant Biotechnology Journal* doi: 10.1111/pbi.14116
9. Amiri H, Banakar MH, Ranjbar GH, Ardakani MRS and Omidvari M (2023). Exogenous application of spermidine and methyl jasmonate can mitigate salt stress in fenugreek (*Trigonella foenum-graecum* L.). *Industrial Crops and Products* **199** doi: 10.1016/j.indcrop.2023.116826
10. An R, Yu R, Xing Y, Zhang J, Bao X, Lambers H and Li L (2023). Enhanced phosphorus-fertilizer-use efficiency and sustainable phosphorus management with intercropping. *Agronomy for Sustainable Development* **43** (5) doi: 10.1007/s13593-023-00916-6
11. Ayesha S, Abideen Z, Haider G, Zulfiqar F, EL-Keblawy A, Rasheed A, Siddique KHM, Khan MB and Radicetti E (2023). Enhancing sustainable plant production and food security: Understanding the mechanisms and impacts of electromagnetic fields. *Plant Stress* **9** doi: 10.1016/j.stress.2023100198
12. Badgery WB, Li G, Simmons A, Wood J, Smith R, Peck D, Ingram L, Durmic Z, Cowie A, Humphries A, Hutton P, Winslow E, Vercoe P and Eckard R (2023). Reducing enteric methane of ruminants in Australian grazing systems – a review of the role for temperate legumes and herbs. *Crop & Pasture Science* doi: 10.1071/CP22299
13. Barrow J, Parvin SA and Debnath A (2023). The effects of pH on phosphorus utilisation by chickpea (*Cicer arietinum*). *Plant & Soil* doi: 10.21203/rs.3.rs-3154831/v1
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Acronyms

ACE	Agribusiness Centre of Excellence
ACIAR	Australian Centre for International Agricultural Research
AEGIC	Australian Export Grain Innovation Centre
AGT	Australian Grain Technologies
AHRI	Australian Herbicide Resistance Initiative
ALBA	Annual Legume Breeding Australia
AM	Arbuscular mycorrhizal
ANSTO	Australian Nuclear Science and Technology Organisation
APRH	Associação Portuguesa de Recursos Hídricos
APSIM	Agricultural Production Systems sIMulator
AR	Augmented reality
ARC	Australian Research Council
ARG	Action Research Groups
ASI	Ammoniated straw incorporation
AUC	Area under the curve
AWP	Australian Water Partnership
BAU	Bangladesh Agricultural University
BITA	Behavioural Insights for Technology Adoption
BMS	Building management system
BPFSP	Best Practice Farming Systems Project, UWA Farm Ridgefield
CAED	UWA Centre for Agricultural Economics and Development
CASI	Conservation Agriculture-based Sustainable Intensification
CCO	Country of origin
Cd	Cadmium
CEI:AgER	Centre for Engineering Innovation: Agriculture & Ecological Restoration
CH_4	Methane
CIAT	International Center for Tropical Agriculture
CIMMYT	International Wheat and Maize Improvement Center
CMCA	Centre for Microscopy, Characterisation and Analysis
CME	Co-operative and Mutual Enterprise
CNV	Gene copy number variation
CO_2	Carbon dioxide
COGGO	The Council of Grain Growers Organisations Limited
CRC	Cooperative Research Centre
CRM	Customer Relationship management
CSBP	Cuming Smith British Petroleum and Farmers Limited
CSC	Chinese Scholarship Council
CSI	Conventional straw incorporation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CV	Cultivar
CWSS	Centre for Water and Spatial Science
CZO	Critical Zone Observation
DBM	Diamondback moth
DEFRA	UK Department of Environment Food and Rural Affairs Development, WA
DHA	Dihydroxyacetone
DNA	Deoxyribonucleic Acid
DOC	Dissolved organic carbon
DOI	Digital Object Identifier
DPIRD	Department of Primary Industries and Regional Development
DSW	Deep soil water
DWER	Department of Water and Environmental Regulation
ECU	Edith Cowan University
EIAR	Ethiopian Institute of Agricultural Research
ERT	Electrical Resistance Tomography
FAAS	Fellow of the Australian Academy of Science
FAIA	Fellow of the Australian Institute of Agriculture
FAIR	Findable, Accessible, Interoperable, Reusable
FAO	Food and Agriculture Organization of the United Nations
FBIP	Farmer Behaviour Insights Project
Fe	Iron
FFQ	Food frequency questionnaires
FTSE	Fellow of the Australian Academy of Technological Sciences
GCMS	Gas chromatography-mass spectrometry
GGA	Grower Group Alliance
GHG	Greenhouse gas
GIWA	Grains Industry Association of WA
GM	Genetically modified
GPC	Wheat grain protein concentration
GPS	Global Positioning System
GRDC	Grains Research and Development Corporation
GWAS	Genome wide association studies
H_2S	Hydrogen Sulfide
HPPD	Hydroxyphenyl pyruvate dioxygenase
HPTLC	High-performance thin-layer chromatography
HTP	High-throughput phenotyping
IAB	Industry Advisory Board
IARI	Indian Agricultural Research Institute
ICA	International Co-operative Alliance
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas
ICIMOD	International Centre for Integrated Mountain Development
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFSD	Institute for Study and Development
IMB	Institute Management Board
IOA	The UWA Institute of Agriculture
K	Potassium
KASP	Kompetitive Allele-Specific PCR
KGF	Krishi Gobeshona Foundation
LA	Lauric acid
LiDAR	Light Detection and Ranging
LLL	Laser Land Leveller
MAP	Mono-ammonium phosphate
MAS	Marker-assisted Selection
MERiL	Methane Emissions Reduction in Livestock
MGO	Methylglyoxal
MLA	Meat & Livestock Australia
MLP	Merino Lifetime Productivity
MoU	Memoranda of Understanding
MTA	Marker-trait associations
MUCP	Malaysia-UNESCO Cooperation Programme
N	Nitrogen
N_2O	Nitrous oxide
NAAS	National Academy of Agricultural Sciences, India
NaCl	Sodium chloride
NACRA	North Australian Crop Research Alliance
NaCRRI	National Crops Resources Research Institute, Uganda
NH_3	Ammonia
NPL	National Project Lead
NPZ	Norddeutsche Pflanzenzucht
NSU	North South University
NSW DPI	New South Wales Department of Primary Industries
NSW	New South Wales
NUFER	Nutrient-use efficiency based fertiliser recommendation method
OCS	Optimal Contribution Selection
OCT	Optical coherence tomography
ORDCO	Ord River District Co-operative Ltd
P	Phosphorus
PABRA	Pan Africa Bean Research Alliance
pH	Potential of hydrogen
PLS-SEM	Partial least squares structural equation modelling
PUFA	Polyunsaturated fatty acids
PVS	Potato virus S
QFD	Quality Function Deployment
QLD	Queensland
QTL	Quantitative trait locus
R&D	Research and Development
RDE&A	Research, Development, Extension and Adoption
RiskWi$e	National Risk Management Initiative
ROO	Region of origin
RSA	Root system architecture
RTP	Research Training Program scholarship
SAgE	UWA School of Agriculture and Environment
SDG	United Nations Sustainable Development Goal
Si	Silicon
SME	Small and medium enterprises
SNP	Single nucleotide polymorphism
SOA	Sulphate of ammonia
SSRE	Super SR Extra
ST	Struvite
STI	Stress tolerance index
SW WA Hub	South-West WA Drought Resilience Adoption and Innovation Hub
SWCP	Soil and water conservation practices
SWS	Soil water storage
TiME	Transformations in Mining Economics
TMF	Texture-modified foods
TOEI	Technology, Organisation, Environment and Individual
UAF	University of Agriculture, Faisalabad, Pakistan
UNE	University of New England
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSW	University of New South Wales
UNTAD	United Nations on Trade and Development
UNTL	National University of Timor-Lorosa'e, East Timor
UPA	University Postgraduate Award
UQ	University of Queensland
USyd	University of Sydney
UWA	The University of Western Australia
UWAAL	UWA Aviation Laboratory
VIC	Victoria
VMS	Vadose-zone Monitoring System
WA	Western Australia
WGRS	Whole-genome resequencing
WSMD/V	Wheat Streak Mosaic Disease/Virus
Zn	Zinc
ZNE	Zero Net Emissions
ZNEAg	CRC Zero Net Emissions from Agriculture CRC

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