THE UNIVERSITY OF WESTERN AUSTRALIA | Institute of Agriculture

Annual Research Report 2022

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.

Font cover image: Harvesting in the WA grainbelt at sunset.
Photo: Janelle Lugge

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The UWA Institute of Agriculture Annual Research Report 2022

Director's overview

On behalf of The University of Western Australia (UWA), I am pleased to present the Annual Research Report 2022 for The UWA Institute of Agriculture (IOA).

This report shines a spotlight on the accomplishments of our affiliated researchers and their collaborators, who published more than 315 journal articles, books and book chapters in 2022. We also celebrate numerous academics named on the annual Highly Cited Researchers list and dozens of researchers who received significant awards and accolades. There is no doubt that these hardworking individuals helped UWA retain its number one spot nationally and move up one place to 15th in the world for Agricultural Sciences in the 2022 Academic Ranking of World Universities.

In 2022, we embarked on an exciting new chapter for research at UWA Farm Ridgefield. To unlock the full potential of research at the farm, the Future Farm 2050 Project was retired, and in its place the Best Practice Farming Systems Project was officially launched. Collaborative and multidisciplinary research and development activities were guided by the leaders of our six Research Themes. In late 2022, we welcomed Professor Sharon Purchase from the UWA Business School as our new theme leader for Agribusiness Ecosystems. On behalf of everyone at the IOA, I extend my sincere gratitude to former theme leaders Professor Megan Ryan and Winthrop Professor Tim Mazzarol for their many years of dedication and support.

Meaningful engagement with UWA's agricultural research, development and training activities continued its upward trend throughout 2022. Our online audiences grew significantly – with LinkedIn followers almost reaching 3000 and Twitter exceeding its growth rate from the previous 12 months. Forty-two media statements related to IOA were distributed, generating excellent coverage in WA, interstate, and international media. About 21,600 people viewed our media statements online, with each 2022 article averaging more than 500 individual views.

Through our communications and events, we continued to improve upon our engagement with industry, farmer groups, collaborators, funding bodies, and alumni. It was an especially busy year for our events calendar, as IOA hosted and contributed to 15 public lectures, forums, seminars, and open days. Following numerous postponements due to the pandemic, I was very glad that the IOA and UWA School of Agriculture and Environment embraced the occasion to properly celebrate Emeritus Professor Graeme Martin's five-decade career teaching and research at UWA with a special symposium and dinner. Continuing this theme of valuable collaboration with SAgE, a particular highlight of 2022 was IOA jointly hosting the UWA Shenton Park Field Station 2022 Open Day. Thank you to the Member for Agricultural Region the Hon Darren West MLC and UWA Vice Chancellor Professor Amit Chakma for opening the event, and to the dozens of researchers, staff and student volunteers who helped make the day such a success.

Upon reflecting on our achievements in 2022, I wish to emphasise that this Institute is strong because of the strength of its people. It is my great pleasure to acknowledge IOA staff, researchers, associates, students, board members, and Research Theme leaders, as well as our national and international collaborators and funding bodies, for their dedication, support, and tireless efforts throughout the year.

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

The UWA Institute of Agriculture
The University of Western Australia

IAB Chair and DVCR messages

I am very proud of the significant contributions that the Industry Advisory Board (IAB) has made in 2022 to build upon the IOA's long-time association and working relationship with the agriculture industry in WA. Our Board, comprised of passionate farmers and representatives from industry leaders, provides advice and support that enhances the value of IOA to our rural and regional communities locally, nationally and beyond.

Although I was unfortunately travelling and unable to attend the 16th annual Industry Forum in July, by all reports it was a very stimulating and thought-provoking event. The topic 'Navigating the Global Agricultural Marketplace in the Indian Ocean Rim: Spotlight on India and Indonesia' was especially pertinent to working farmers and members of the WA agriculture industry in the audience who were focused on developing and improving upon our trade, investment and economic relationships with these important neighbouring countries. Each year, the IAB forms a planning subcommittee to identify the topic and expert speakers for our Industry Forum. I especially wish to thank the CSBP and Farmers Golden Jubilee of Agriculture Science Fellowship held at UWA for their continual sponsorship of this event.

I extend my congratulations to the IOA for co-hosting the first public open day in a decade at the UWA Shenton Park Field Station in September. There are numerous research projects underway at the field station that have important connections with government and industry, many of which are featured in this report. They include Future Green Solutions and AquaticAI in the Aquaculture Facility, 20 years of canola research with NPZ, DLF Seeds work with UWA's Annual Legume Breeding Australia, and dozens of industry networks through the newly launched Centre for Engineering Innovation: Agriculture & Ecological Restoration, Australian Herbicide Resistance Initiative, and Coastal and Offshore Engineering Laboratory.

I look forward to the IAB continuing to partner with IOA to achieve our shared goals in 2023 and beyond. 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 University of Western Australia is proud to celebrate its impressive international reputation in the fields of agriculture and related areas. Not only was our university ranked 15th in the world for agricultural science in 2022, but among the 17 UWA researchers named in the prestigious worldwide Highly Cited Researcher list, more than half work in agriculture and related areas.

There is no doubt that the IOA has played a significant role in achieving this global reputation. 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.

As you turn the pages of this impressive Annual Research Report 2022, you will read about numerous innovative projects and initiatives that our UWA researchers have undertaken to address important global challenges of food security and sustainable agriculture. The IOA fosters industry partnerships and communicates its research outcomes through their interactions with grower groups, industry leaders, government bodies, fellow UWA institutes and schools, and the public to prioritise representative, impactful research that will genuinely make a difference in our world.

I was delighted to present opening speeches at two of the IOA's public events in 2022. At the 16th annual Postgraduate Showcase in June, it was inspiring to meet the six outstanding postgraduate students presenting their research findings. The following month, celebrating Emeritus Professor Graeme Martin's 50-year milestone at UWA was a particularly special and moving event. Professor Martin is one of those scholars whose work has underpinned the amazing achievements of agricultural research at UWA and in this State. I was honoured to thank and acknowledge him on behalf of the University.

The IOA is dedicated to translating its research outcomes and engagement activities through regular media statements, social media, events, and publications. This Annual Research Report 2022 is a comprehensive publication that I believe will lead to information exchange, new collaborations and overall positive outcomes for the University and agricultural sector.

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

Aerial shot of grain harvesting in WA.
Photo: Janelle Lugge

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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, as well as with 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 through the inclusion of postgraduate students, commonly Masters by coursework and dissertation project students and PhD students.

As is evident from the projects included 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 very 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). The means by which crop nutrient acquisition can be enhanced, particularly that of phosphorus and nitrogen, are 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

Professor Megan Ryan
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Dr Nicolas Taylor
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Professor Jacqueline Batley
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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], Dr Fiona Dempster[1], Associate Professor Matthias Leopold[1], Professor Daniel Murphy[2]

Collaborating organisations: [1]UWA; [2]Murdoch University; SoilsWest

Semi-open passive chambers used to measure ammonia volatilisation rates following the application of ammonium sulphate to the soil surface.

Increased investment in fertiliser N by grain growers has increased the imperative for fertiliser N use efficiency. Anecdotal evidence suggests broadcasting lime and ammonium sulphate (SOA) 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 is investigating whether applying SOA (100 kg N/ha) to soils that are:

a) Limed (2.5 t/ha of lime sand) prior to planting canola (*Brassica napus* cv. ATR Stingray) (Experiment 1), or
b) Containing residual lime (and having been 'cropped' once with canola) and planted to barley (*Hordeum vulgare* cv. *Spartacus* CL) (Experiment 2)

Increases the potential for ammonia volatilisation, and in turn decreases crop productivity and N uptake under two contrasting 'break-of-season' rainfall scenarios.

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

Our first experiment showed applying lime and SOA 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 <1 per cent to 20 per cent of fertiliser N applied, depending on soil and treatment. Greatest losses from both soil types occurred when SOA application onto a recently limed soil coincided with a series of 1 mm simulated rainfall events. The extent of ammonia volatilisation from the limed soil significantly decreased (<7 per cent) if simulated rainfall immediately after SOA application was increased to 20 mm. The growth and grain yield of the canola was not negatively impacted by the loss of N via ammonia volatilisation as there was sufficient plant-available N to maintain plant growth.

Our first experiment demonstrates that growers applying lime and SOA in close succession to the soil surface prior to seeding risk losing a significant amount of the N applied via ammonia volatilisation depending on the amount and timing of rainfall.

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

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

Launch of the digital SOILHEALTH app

Project team: Emerita Professor Lynette Abbott[1] (project leader; lynette.abbott@uwa.edu.au), Cheryl Rimmer[1], Alex Lush[2], Angela Rossen, Paul Rigby, Peter Clifton[3]

Collaborating organisations: [1]UWA; [2]Lush Digital; [3]South West Catchments Council

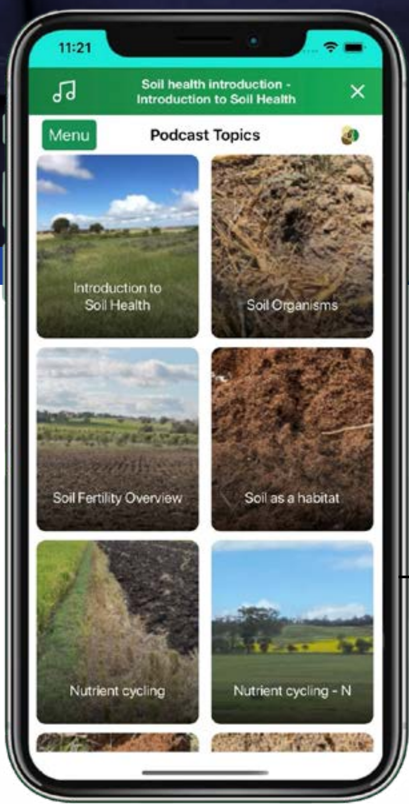
The University of Western Australia Emerita Professor Lynette Abbott officially launched her SOILHEALTH app at a special ceremony in May 2022. The app, which is available to download for free on IOS and Android phones and tablets via Apple and Google Play, is a culmination of five decades of soil biological health research. It was funded by the Australian Government's National Landcare Program Smart Farms Small Grants to provide essential information about complex aspects of soil health in a digital format.

Features of the SOILHEALTH app include an eBook, podcasts, and seven soil health animations custom-created by Lush Digital. Australian farmers are the main target audience; however, the app can be used by anyone interested in soil health, including teachers, students, and gardeners.

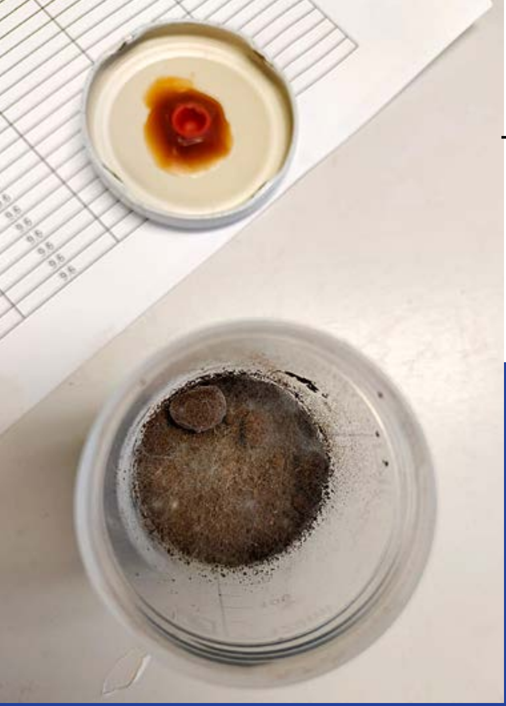
Communications Officer Cheryl Rimmer, who first suggested the SOILHEALTH app in 2019, coordinated the app development. UWA Farm Ridgefield researchers and staff assisted with the development of the eBook. Artwork by Angela Rossen and photographs by Paul Rigby complement the science. Regional Agriculture Landcare Facilitator Peter Clifton from South West Catchments Council collaborated in the review and delivery of the app within the community.

This research is supported by Australian Government's National Landcare Program Smart Farms Small Grants.

UWA Emerita Professor Lynette Abbott displaying the SOILHEALTH app.



A screengrab of podcast topics from the SOILHEALTH app.



Novel fertiliser product formed by combining lauric acid with microalgae biomass.

Development of a controlled release fertiliser by incorporating lauric acid into microalgal biomass: Dynamics on soil biological processes for efficient utilisation of waste resources

Project team: Dr Sasha Jenkins[1] (project leader; sasha.jenkins@uwa.edu.au), Dr Bede Mickan[1,2], Kautilya Srivastava[1], James O'Connor[1], Sun Kumar Gurung[3], Navid Moheimani[3]

Collaborating organisations: [1]UWA; [2]Richgro; [3]Murdoch University

Utilisation of microalgae to extract nutrients from the effluent of anaerobic digestion of food waste is an emerging technology. A by-product of this process is the microalgal biomass which has potential to be used as an organic bio-fertiliser. However, microalgal biomass are rapidly mineralised when applied to soil which may result in N loss. One solution is to emulsify microalgal biomass with lauric acid (LA) to delay the release of mineral N.

This study aimed to investigate whether combining LA with microalgae to develop a new fertiliser product with a controlled release function of mineral N when applied to soil, and any potential impacts the bacterial community structure and activity. The treatments were applied to soil emulsified with LA and were combined with either microalgae or urea at rates of 0 per cent, 12.5 per cent, 25 per cent and 50 per cent LA, untreated microalgae or urea and unamended control were incubated at 25°C and 40 per cent water holding capacity for 28 days.

Collecting headspace gas to measure carbon dioxide production (microbial respiration).

Quantification of soil chemistry (NH_4^+- N, NO_3–N, pH and EC), microbial biomass carbon, CO_2 production and bacterial diversity were characterised at 0, 1, 3, 7, 14 and 28 days. The NH_4^+-N and NO_3–N concentration decreased with increasing rate of LA combined microalgae indicating that both N mineralisation and nitrification were impacted. As a function of time, NH_4^+- N concentration increased up to seven days for the microalgae at lower rates of LA, and then slowly decreased for 14 and 28 days, with an inverse relationship with soil NO_3–N. Aligning with soil chemistry, an observed decrease in the predicted nitrification genes amoA×amoB and relative abundance of ammonia oxidising bacteria (*Nitrosomonadaceae*) and nitrifying bacteria (*Nitrospiraceae*) with an increasing rate of LA with microalgae provides further support for possible inhibition of nitrification. The MBC and CO_2 production was higher in the soil amended with increasing rates of LA combined microalgae and there was an increase in the relative abundance of fast-growing heterotrophs.

Treating microalgae by emulsification with LA has the potential to control the release of N by increasing immobilisation over nitrification and therefore it might be possible to engineer microalgae to match plant nutrient growth requirements whilst recovering waste from waste resources.

This research was first published in the *Journal of Environmental Management*. See page 136, citation 229.

This research is supported by the Smart farming partnerships Round 2 (project SFP2-4-D59GK49), through funding from the Australian Government's National Landcare Program.

Large trenches dug into soil and filled with biochar, compost and other organic amendments, with native seedlings planted in smaller adjacent trenches.

Restoration of a severely degraded landscape using compost and biochar: Impacts on plant growth, and soil biological and chemical processes

Project team: Emerita Professor Lynette Abbott[1] (project leader; lynette.abbott@uwa.edu.au), Cassandra Howell[1], Dr Sasha Jenkins[1], Dr Bede Mickan[1]

Collaborating organisations: [1]UWA; National Landcare Program

Most large farms encompass a wide diversity of landscapes and ecosystems. While not every area is suitable for cropping or running stock, each area contributes to the overall health and function/productivity of the farmland. This project contributed to improving the condition of soil which is subjected to degradation by salinity and erosion. It focused on protecting and improving soil on pockets of land which would otherwise be low grade and non-profitable pasture. In this case it addressed an isolated saline seep on UWA Farm Ridgefield. Such small but highly degraded areas can contribute to the progression of salinity in adjacent paddocks and other areas of the farm. Restoring or remediating these areas can help to restrict the movement of salinity and provide small areas of vegetation that can be periodically grazed. Given the severe degradation and multiple constraints present in these areas, the soil conditions can cause difficulty for establishing trees for restoration. Therefore, additional remediation activities are required to achieve positive outcomes in the long term.

Supported by a National Landcare Program Smart Farms Grant 'Farm Demonstration to fast-track restoration of soil condition using permeable biomass barriers', the project explored the use of organic amendments in restoring vegetation and soil quality associated with a highly saline, degraded seep area. It was proposed that these amendments could reduce the impact of salinity and nutrient-related constraints, improving soil condition, stimulating bacterial activity and improving the establishment, survival and growth of native plant species.

Based at UWA Farm Ridgefield, the project included both a field and glasshouse experiments to explore the use of compost, biochar and other organic amendments

The field experiment consisted of two approaches:

a) Holes (permeable wells) were dug alongside existing vegetation (from past revegetation project) and filled with a mixture of organic amendments, and
b) Long trenches (permeable walls) were dug perpendicular to the slope of the site and filled with multiple organic amendments and with native seedlings planted between the trenches.

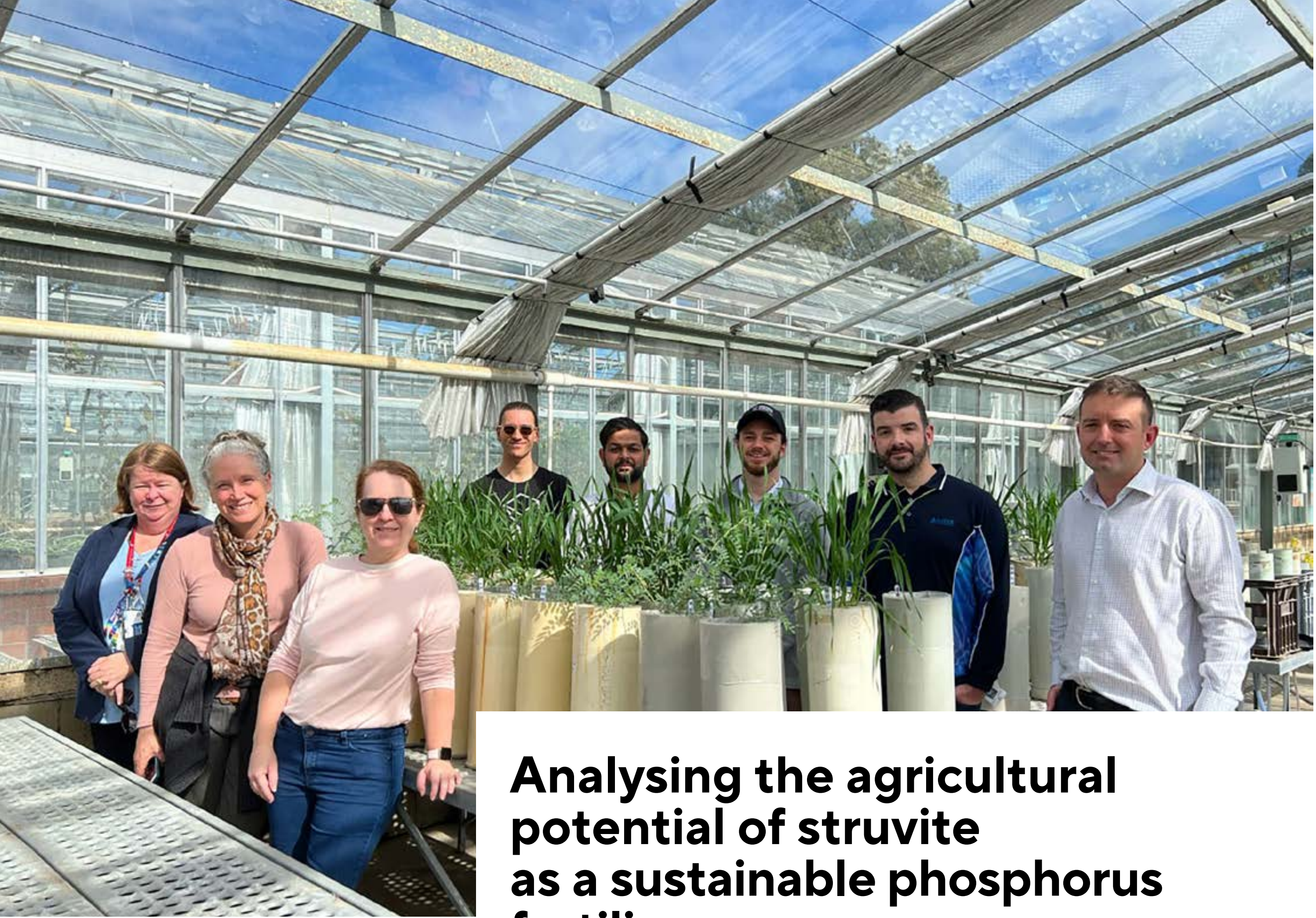
The glasshouse experiment used soil from the field site mixed with different organic amendments. Saltbush seedlings were grown in the amended and unamended soil. The organic amendment mixes comprised of different combinations of compost and/or biochar, applied at different rates.

The experiments assessed the impact of amendment use on plant survival and growth, as well as impacts on soil biological and chemical properties. Positive outcomes were observed in both experiments, particularly in relation to the survival of new seedlings. Compost had a highly beneficial effect on plant growth, microbial activity and soil condition, while biochar had some positive effect on soil chemistry.

This study demonstrated the potential for using soil biological amendments during the initial stages of restoring vegetation on small localised severely degraded areas to stabilise the soil conditions and prevent further spread of erosion and land degradation.

This research is supported by UWA and the National Landcare Program – Smart Farms Small Grants Round 2.

Saltbush (*Atriplex nummularia*) grown in field soil amended with different combinations of biochar and compost.



Ben Stone and Leanne Brown from the Water Corporation visited PhD candidate Manish Sharma's glasshouse experiments with UWA researchers Evonne Walker, Professor Megan Ryan, Dr Bede Mickan, George Mercer and Andreas Pfeifle.

Analysing the agricultural potential of struvite as a sustainable phosphorus fertiliser

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]

Collaborating organisations: [1]UWA; Water Corporation

Could a recycled phosphorus (P) fertiliser derived from human wastewater known as 'struvite' be the next big breakthrough in agriculture? For a project funded by the Department of Agriculture, Water and the Environment, UWA PhD candidate Manish Sharma is evaluating struvite's potential as a sustainable P fertiliser.

The essential nutrient P is primarily found in phosphate rock reserve – which is limited, non-renewable and will exhaust in next few centuries. Struvite is a crystalline compound of magnesium ammonium phosphate derived from recycled human wastewater via a precipitation process. It contains significant amounts of macronutrients and small quantities of micronutrients.

The level of heavy metals and pathogens in struvite was lower than in commercial fertilisers, and therefore has a great potential to be used as an alternative P fertiliser. Due to its low solubility compared to commercially used P fertilisers, struvite also has significant environmental sustainability benefits by minimising the risk of eutrophication.

The Water Corporation conducted a pilot trial at their waste treatment plant and recovered some struvite which they provided samples to Mr Sharma to test struvite's fertiliser value. His first-year short-term glasshouse trial produced promising results, suggesting that struvite has great potential as a substitute for soluble P fertiliser for the growth of chickpea and wheat. These research findings will help the Water Corporation to create a market for struvite in Australia. In the second half of 2022, Mr Sharma compared struvite with commercially used P fertiliser provided by CSBP Limited and growing crops to grain maturity.

This research is supported by UWA, the Department of Agriculture, Water and the Environment, and the AW Howard Memorial Trust Tim Healey Memorial Scholarship.

Uneven crop residue distribution influences soil chemical composition and crop yield under long-term no-tillage

Project team: Dr Philip Ward[1,2], Professor Ken Flower[1] (project leader; ken.flower@uwa.edu.au), Nikala Passaris[1], Neil Cordingley[3]

Collaborating organisations: [1]UWA; [2]CSIRO; [3]Western Australian No-Tillage Farmers Association; GRDC; Western Australian College of Agriculture, Cunderdin

Conservation agriculture has three main components: crop residue retention; minimal soil disturbance; and diverse rotations. Whilst retaining crop residues on the soil surface is important to prevent erosion and conserve water, high residue amounts can also have negative effects. Residue spread behind harvesters is not always uniform, therefore, it is important to understand the impact of uneven residue spread on crop performance. These problems are likely to increase as more farmers windrow and burn residues for weed control, harvesters become larger and controlled traffic systems are implemented.

The effect of residue distribution on soil properties and crop establishment and yield was studied under no-tillage and controlled traffic in cereal (wheat-wheat-barley) and diverse (wheat-legume-canola) rotations, over the final six years of a larger 12-year (2007–2018) rotation trial, in the Wheatbelt of Western Australia. Within each crop and rotation, residue management consisted of either spreading or windrow-burning and measurements were taken from three locations relative to the harvester wheel tracks: centre (between harvester wheel tracks), mid (2.25 m perpendicular) and outer (4.5 m perpendicular), representing the ~9 m working width of the machinery.

In most years, the distribution of crop residue behind the harvester was uneven, with up to twice as much residue directly behind the harvester compared with mid and outer locations. Differences in residue amount had positive, negative or no effect on crop establishment and yield, depending on the crop and residue type and climatic conditions. Increasing residue amount had a positive effect on establishment and yield when conditions were dry around seeding and early crop growth stages, possibly associated with increased water availability with increased residue load. Conversely, there were negative effects when frost occurred at anthesis or under high rainfall conditions, the latter due to physical impairment, increased disease or lack of available nitrogen. Negative effects only occurred with cereal residue and could be minimised by growing more break crops, even under high residue loads. In the longer term, higher residue amounts resulted in increased soil nutrients behind the harvester, which increased yields in some years.

Therefore, research to improve uniformity of residue spread behind harvesters is crucial. Otherwise, variation in crop performance will increase as harvesters get bigger and, in the long term, periodicities in soil chemistry under controlled traffic systems will occur.

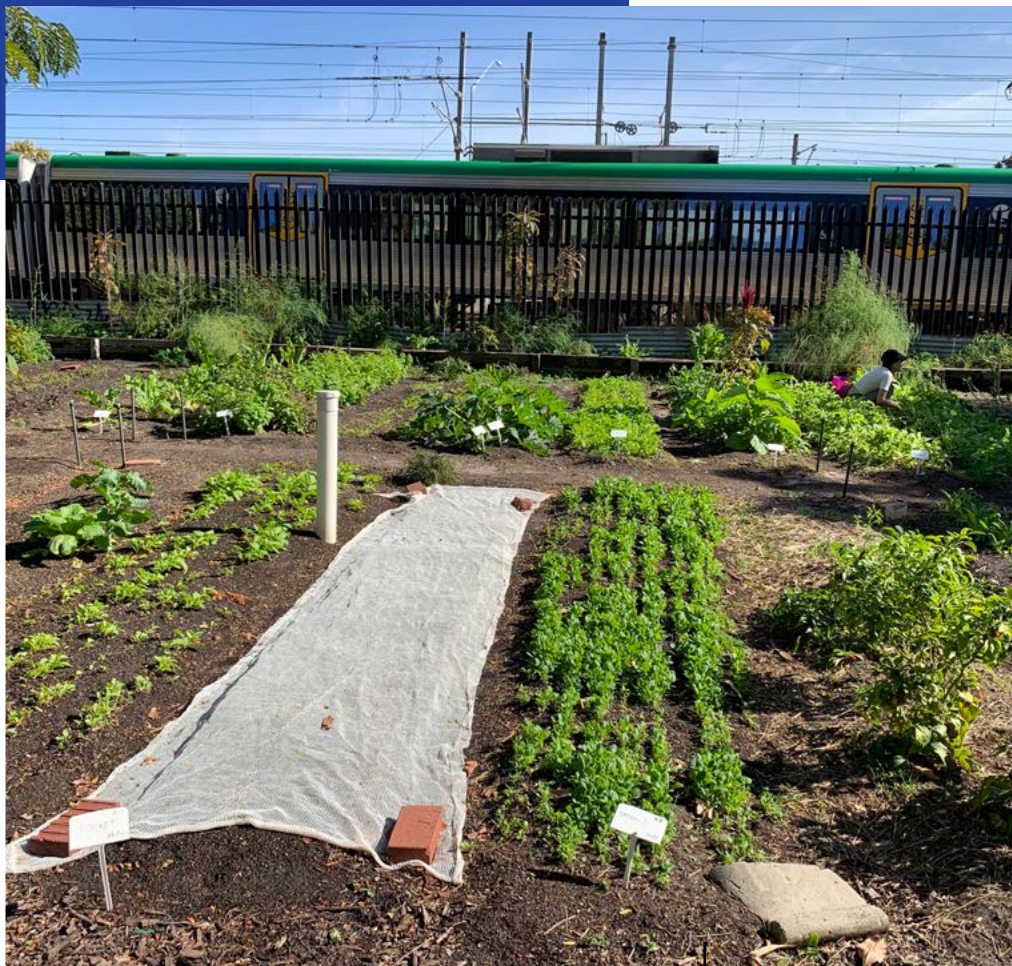
This research is supported by UWA and GRDC.

Harvesting at the long term rotation.

Soil health and carbon storage in Perth community gardens

Project team: Haochen Zhao[1], Professor Nanthi Bolan[1] (project leader; nanthi.bolan@uwa.edu.au), Dr Bede Mickan[1]

Collaborating organisations: [1]UWA; Perth City Farm; North Fremantle Social Farm; Murdoch Community Garden; West Leederville Community Garden; Earthwise Community; Glyde-In Garden Gnomes



Plentiful crops growing at Perth City Farm.

UWA Honours student Haochen Zhao with Professor Nanthi Bolan.

Community gardens provide a common space where people come together to grow food, foster good health, and green urban environments, support life-long learning and cultivate vibrant communities.

UWA Honours student Haochen Zhao examined soil health and carbon storage in community gardens located in the Perth metropolitan area. His research project was supervised by Professor Nanthi Bolan and Dr Bede Mickan, and included Perth City Farm, North Fremantle Social Farm, Murdoch Community Garden, West Leederville Community Garden, Earthwise Community and Glyde-In Garden Gnomes.

Although community gardens primarily promote sustainable horticulture and conservation agriculture practices, research on soil health and carbon sequestration potential in community gardens was limited. Soil carbon sequestration contributes to mitigating the impacts of climate change resulting from greenhouse gas emissions.

For this study, soil samples were collected from the six community gardens covering three Soil Mapping Units (calcareous deep sands, coloured sand, pale sands) including control plots (bare ground next to raised beds) and raised beds (gardening area). Soil samples of raised beds and control plots were characterised for various soil physical, chemical and biological properties. Soil carbon storage was then calculated based on bulk density and the total carbon content of the soil.

The soil samples from raised beds had lower bulk density and loamy texture. They also had higher pH buffering capacity, available nutrients (including nitrogen phosphorus and potassium), cation exchange capacity, total carbon, and microbial biomass. This indicated that soils in community gardens maintained higher soil health parameters.

In addition, raised bed soils accumulated higher levels of carbon, indicating that community gardens provide a potential source of carbon sequestration. The improved soil health and carbon storage in community garden soil can be attributed to the regular application of compost produced within the community gardens.

This research is supported by UWA.

Decreased carbon footprint and increased grain yield under ridge–furrow plastic film mulch with ditch-buried straw returning: A sustainable option for spring maize production in China

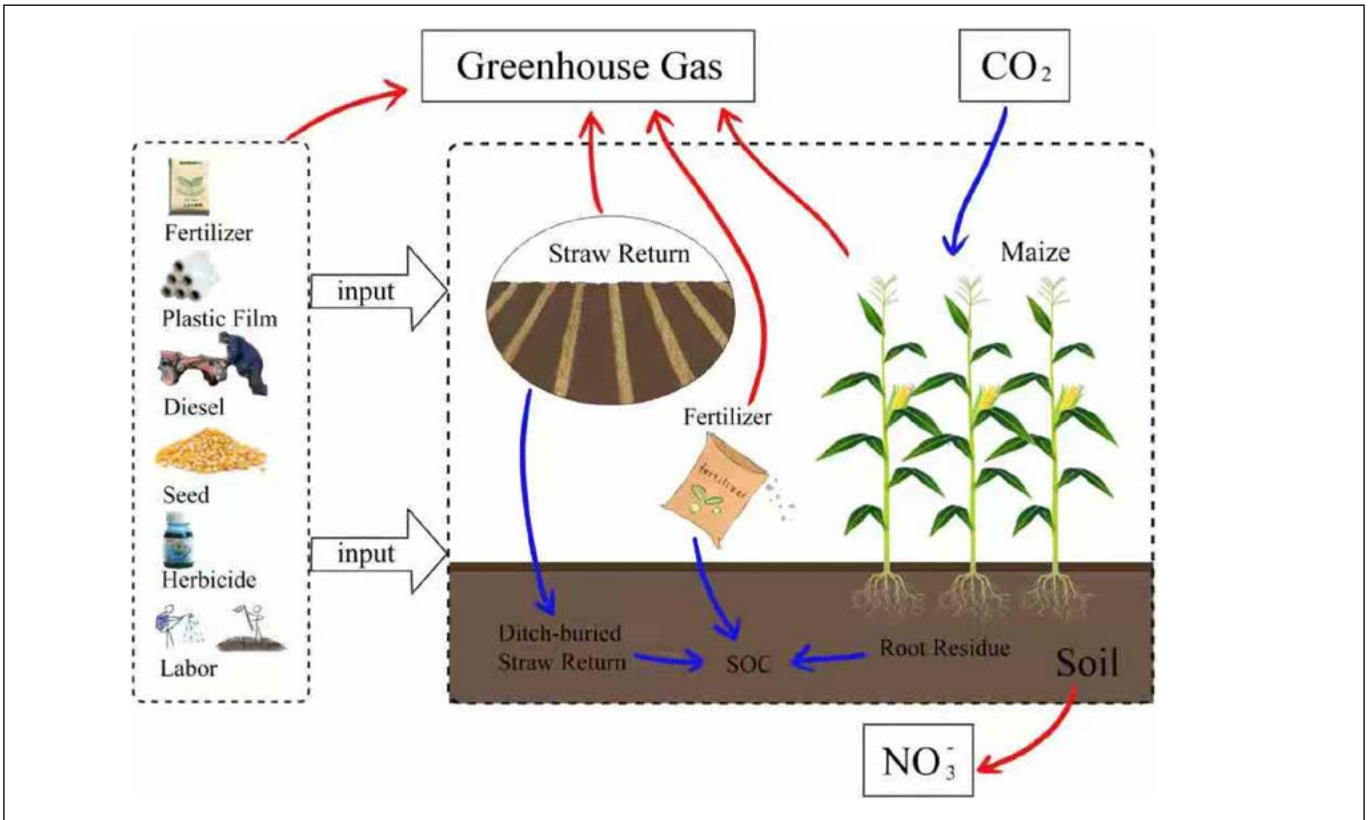
Project team: Professor Miaomiao Zhang[2], Dr Xiaoqing Han[2], Dr Pengfei Dang[2], Hongyu Wang[2], Yijie Chen[2], Professor Xiaoliang Qin[2] (project leader; qinxiaoliang@nwsuaf.edu.cn), Hackett Professor Kadambot Siddique[1]

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

Ditch-buried straw returning with ridge–furrow plastic film mulch (RP+S) is a novel tillage measure in semiarid regions, but it is unclear whether RP+S can increase maize yield while reducing the carbon footprint (CF). Therefore, a six-year continuous experiment was conducted from 2016 to 2021 to quantify the effect of four straw returning and film mulching measures conventional flat cultivation (CK), conventional flat cultivation with ditch-buried straw returning (CK+S), ridge–furrow plastic film mulch (RP), and RP+S] on soil organic carbon sequestration (SOCS), greenhouse gas (GHG) emissions, CF, and economic benefits.

In our six-year experiment, RP+S had the highest maize yield, water use efficiency, partial factor productivity of N fertiliser, revenue, and net returns and relatively higher yield stability than the other three treatments. Straw returning and film mulching measures significantly increased agricultural inputs and total GHG emissions. RP+S had the highest total GHG emissions, mainly due to diesel and plastic film inputs, but the lowest CF and CF per net return. After six years, RP decreased the surface SOC content from 0 to 20cm, increasing net GHG emissions. The straw returning measures significantly increased SOC storage from 0 to 40cm and spring maize yield, offsetting the increased GHG emissions. RP+S, with its high maize yield and net returns, also increased carbon sequestration and reduced GHG emissions and the CF for maize production. Therefore, RP+S is conducive to improving soil fertility, productivity, and economic benefits and alleviating the environmental impact and climate change. In future, the successful development of agricultural machinery for film mulching and ditch-buried straw returning will enable the large-scale promotion and application of RP+S.

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



System boundary of life cycle analysis for estimating carbon footprints. Red arrows indicate carbon emissions, and blue arrows indicate carbon sequestration.

Biochar incorporation increases winter wheat (*Triticum aestivum L.*) production with significantly improving soil enzyme activities at jointing stage

Project team: Associate Professor Yue Li[2,3], Professor Hao Feng[2,4], Dr Ji Chen[3], Dr Junsheng Lu[2], Dr Wenjie Wu[2,3], Dr Xuezhi Liu[2,3], Associate Professor Cheng Li[2], Dr Qin'ge Dong[2,4] (project leader; qgdong2011@163.com), Hackett Professor Kadambot Siddique[1]

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

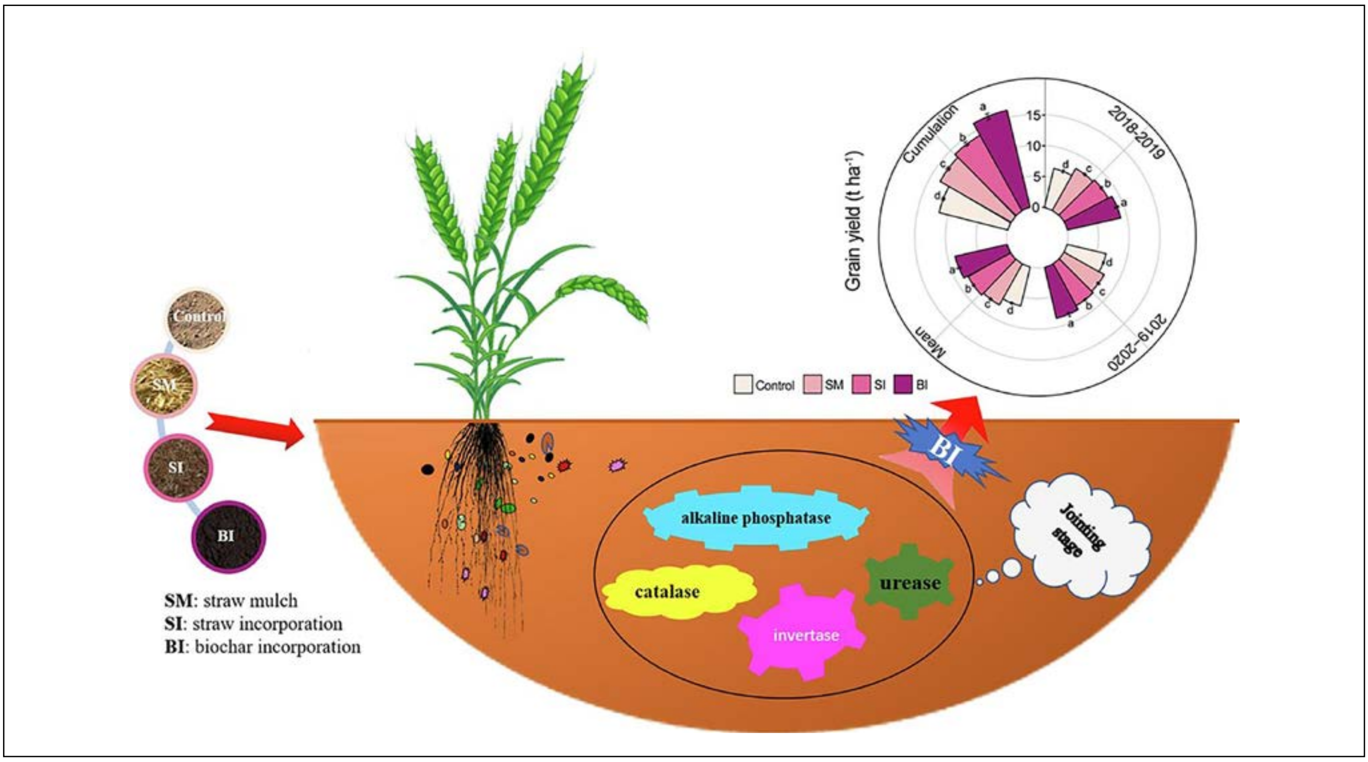
The responses of yield production and soil nutrients availability to agricultural organic inputs are crucial for cropland management. However, the simultaneous impacts of straw-derived biochar and straw addition on yield production and soil properties (e.g., soil enzyme activities at winter wheat growing stages) as well as their potential relationships remain poorly evaluated in semi-arid areas.

Here, a field experiment based on the long-term study (i.e., commenced in 2011) was conducted in the semi-arid Chinese Loess Plateau to explore the responses of soil water storage (SWS), winter wheat (*Triticum aestivum L.*) yield and a range of soil biochemical properties to straw-derived biochar and straw addition in 2018–2019 and 2019–2020. The four treatments were:

1) No straw and no biochar (Control),
2) Conventional straw mulching (SM),
3) Straw incorporated into the soil (SI), and
4) Straw-derived biochar incorporated into the soil (BI).

We found that the BI treatment on average increased SWS in 0–160 cm soil depth by 13 per cent, 17 per cent, and 21 per cent across entire growing seasons, respectively, when compared to the SM, SI and Control treatments. Enhancements in grain yield and aboveground biomass were related to the BI treatment-induced increases in soil carbon and nitrogen content. The BI treatment had higher soil enzyme activities at jointing stage than at grain filling and maturity stages during winter wheat growing seasons. The mixed-effects models showed there were significant effects of growth stage and soil depth on soil microbial biomass and soil dissolved organic carbon and nitrogen, even when analysed by each growing season. Moreover, no significant relationships were found between SWS and soil enzyme activities (invertase, urease, catalase, and alkaline phosphatase). Therefore, straw-derived biochar incorporation could be one of the appropriate practices for increasing crop yield and sustaining soil fertility in the Chinese Loess Plateau and other areas with similar climates.

This research is supported by key R&D projects of Shaanxi Province, the National Natural Science Foundation of China, and 111 Project of the Ministry of Education and the State Administration of Foreign Experts Affairs.



The graphical abstract for this long-term study in the semi-arid Chinese Loess Plateau.

Ammoniated straw incorporation increases wheat yield, yield stability, soil organic carbon and soil total nitrogen content

Project team: Associate Professor Yue Li[2,3], Professor Hao Feng[2,3,4] (project leader; nercwsi@vip.sina.com), Dr Qin'ge Dong[2,3,4], Dr Longlong Xia[2,5], Jinchao Li[2], Cheng Li[2], Associate Professor Huadong Zang[6], Professor Mathias Neumann Andersen[4], Professor Jørgen Eivind Olesen[4], Professor Uffe Jørgensen[4], Hackett Professor Kadambot Siddique[1], Ji Chen[4]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]Chinese Academy of Sciences and Ministry of Water Resources, China; [4]Aarhus University, Denmark; [5]Karlsruhe Institute of Technology, Germany; [6]China Agricultural University, China

Straw management strategies are highly important for maximising the benefits of straw incorporation, which should aim to increase crop production while improving soil fertility. Ammoniated straw incorporation may be one of the potential candidates for achieving these goals. However, the effects of ammoniated straw incorporation on wheat yield, yield stability and soil properties as well as their potential relationships remain poorly understood. Based on an ongoing long-term field experiment commenced in 2011 on the Chinese Loess Plateau, we investigated the responses of soil properties, wheat yield and yield stability of winter wheat (*Triticum aestivum L.*) to ammoniated and conventional straw incorporation during 2017–2020. The three treatments were:

1) No straw (control),
2) Conventional straw incorporation (CSI), and
3) Ammoniated straw incorporation (ASI).

We found that the ASI treatment on average significantly increased wheat yield by 10.1 per cent and yield stability by 19.5 per cent compared to the CSI treatment, and significantly increased wheat yield by 26.9 per cent and yield stability by 38.7 per cent compared to the Control treatment. Changes in wheat yield and yield stability were positively related to ASI-induced increases in soil water storage. When compared to the Control and CSI treatments, the ASI treatment on average significantly increased soil organic carbon (SOC) content by 17.2 per cent and 14.2 per cent and total nitrogen (TN) content by 27.3 per cent and 18.3 per cent in 0–10 cm depth, and it significantly increased SOC content by 19.2 per cent and 12.4 per cent and TN content by 27.8 per cent and 19.4 per cent in 10–20 cm depth, respectively. There were positive relationships between changes in wheat yield and SOC and TN content. These results demonstrate that it is feasible to achieve higher wheat yield and yield stability while increasing SOC and TN content by optimising straw management practices in semi-arid areas.

This research is supported by the National Key R&D Program of China, Natural Science Foundation of China, Key R&D projects of Shaanxi Province, China and the 111 Project of the Ministry of Education and the State Administration of Foreign Experts Affairs of China.

Standing and slashed wheat stubble in the field.

Native plants demonstrating biodiversity at Weelhamby Farm.

Development of Biodiversity Baseline Asset Mapping of Weelhamby Farms providing level 1 Accounting standard for Accounting for Nature (AfN) and Natural Capital Accounting (NcA), providing farm baseline data to achieve 'Biodiversity Credits'

Project team: Associate Professor Judith Fisher[1,2,4] (project leader; judith.fisher@uwa.edu.au), David Martin[3]

Collaborating organisations: [1]UWA; [2]Fisher Research Pty Ltd; [3]Weelhamby Farm; [4]Stormflower Vineyard; International Union for the Conservation of Nature

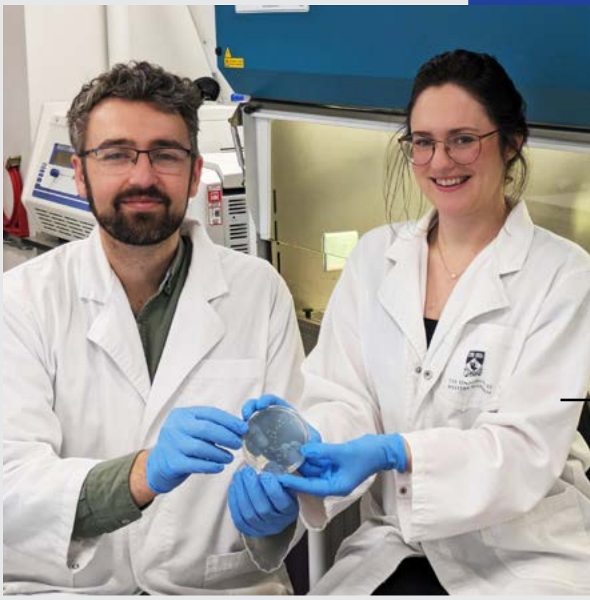
Associate Professor Judith Fisher of The UWA Institute of Agriculture and Director of Fisher Research Pty Ltd was commissioned by Weelhamby Farm's David Martin to advance, and implement, a baseline biodiversity or natural asset mapping of remnant vegetation within the farm. Weelhamby Farm is located near Perenjori in the north-east of Western Australia's wheatbelt. The total farm area is 5,500 hectares; approximately 1,200 hectares of which is remnant vegetation. Weelhamby has a significant carbon project which seeks to demonstrate the viability of carbon farming in a low rainfall area while operating a profitable mixed-farming operation using holistic cropping and animal practices and multispecies pasture. The methodology used has been researched and advanced for agriculture systems following its development and implementation in over 35 biodiverse reserves of differing ecological types. The purpose of the field biodiversity mapping is to establish a baseline biodiversity flora and fauna database to measure change over time, thus enabling future ecological and economic assessments of the effectiveness of Weelhamby Farms' management and/or restoration efforts. The method and results reported align with Level 1 Accreditation for Accounting for Nature (AfN) with the data quality delivering efficacy, high confidence levels, and a robust and unbiased assessment of the condition of the Weelhamby Farm biodiversity assets. The analysis of the data collected also provides Weelhamby Farm with significant data relevant for future biodiversity credits and natural capital accounting needs.

Twenty-five indicators have been mapped across all the differing plant communities. Comparison of results for differing mapped indicators such as weed cover (Fig 1), vegetation condition and levels of disturbance indicates that all three indicators are not aligned, demonstrating the differing impacts of individual indicators, for example areas with low weed cover values may have poor condition levels and low- medium levels of disturbance. This knowledge advances the direct intervention types which are most likely to be most effective in restoring biodiversity. The Geographic Information System resulting from the field data includes all data collected for the 25 Indicators across the differing plant community types. Analyses can be conducted on any number of indicators and their interlinkages, advancing management options and understandings of change in the assets over time. Incorporation of economic costs by the farm managers enable further understandings of the success or otherwise of actions and their costs.

The biodiversity asset database aligns with the high-quality best practice approaches being employed by Weelhamby owners and managers and their significant carbon project.

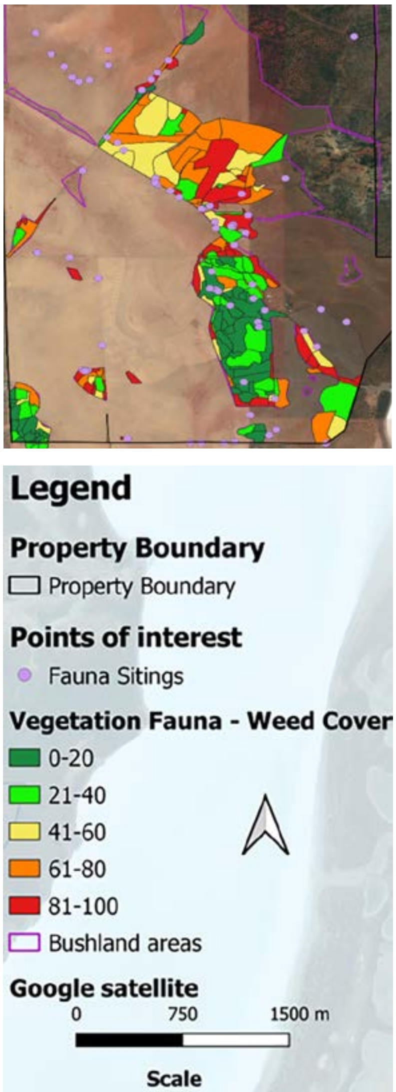
This research is supported by UWA and Weelhamby Farm.

Cropping at Weelhamby Farm.



Jaco Zandberg and Sam Harvie with the Young People in Agriculture, Fisheries and Forestry prize.

Weed cover levels at Weelhamby Farm.



Development of a spray using 'anti-ice-nucleating' vesicles to protect crops from frost damaging bacteria

Project team: Samantha Harvie[1] (project leader; samantha.harvie@research.uwa.edu.au), Jaco Zandberg[1]

Collaborating organisation: [1]UWA

Severe frost damage in grain crops costs Australian farmers an estimated $400 million annually. Bacteria (known as *Pseudomonas*) produces proteins that raise the temperature at which water freezes in the environment. It means frost damage can occur at temperatures as high as -2°C, rather than the -8°C to -10°C usually needed in the field.

UWA PhD candidates Samantha Harvie and Jaco Zandberg jointly developed this research project idea that won Mr Zandberg the prestigious Young People in Agriculture, Fisheries and Forestry prize at the 2022 Science and Innovation Awards in February. The $22,000 grant will fund the one-year proof of concept research to develop a spray that uses 'ice-nucleating' bacteria to protect crops from frost damage.

The project will explore whether those vesicles can be used to carry interference molecules that will temporarily shut down production of ice-nucleating proteins. The vesicles produced will be naturally degradable, non-toxic and non-GMO. They will be easy-to-use, naturally forming structures that can capture the interference molecules and deliver them to the ice-nucleating bacteria.

The aim of this project is to use the novel technology to develop an easy-to-use spray that can be applied when a frost event is forecast to suppress the ice nucleating activity. The spray will be designed specifically for growers and farmers to use easily and without the need for specialised equipment, in effect reducing the devastating and costly damage caused by frost events.

This research is supported by UWA and the Australian Government.

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]

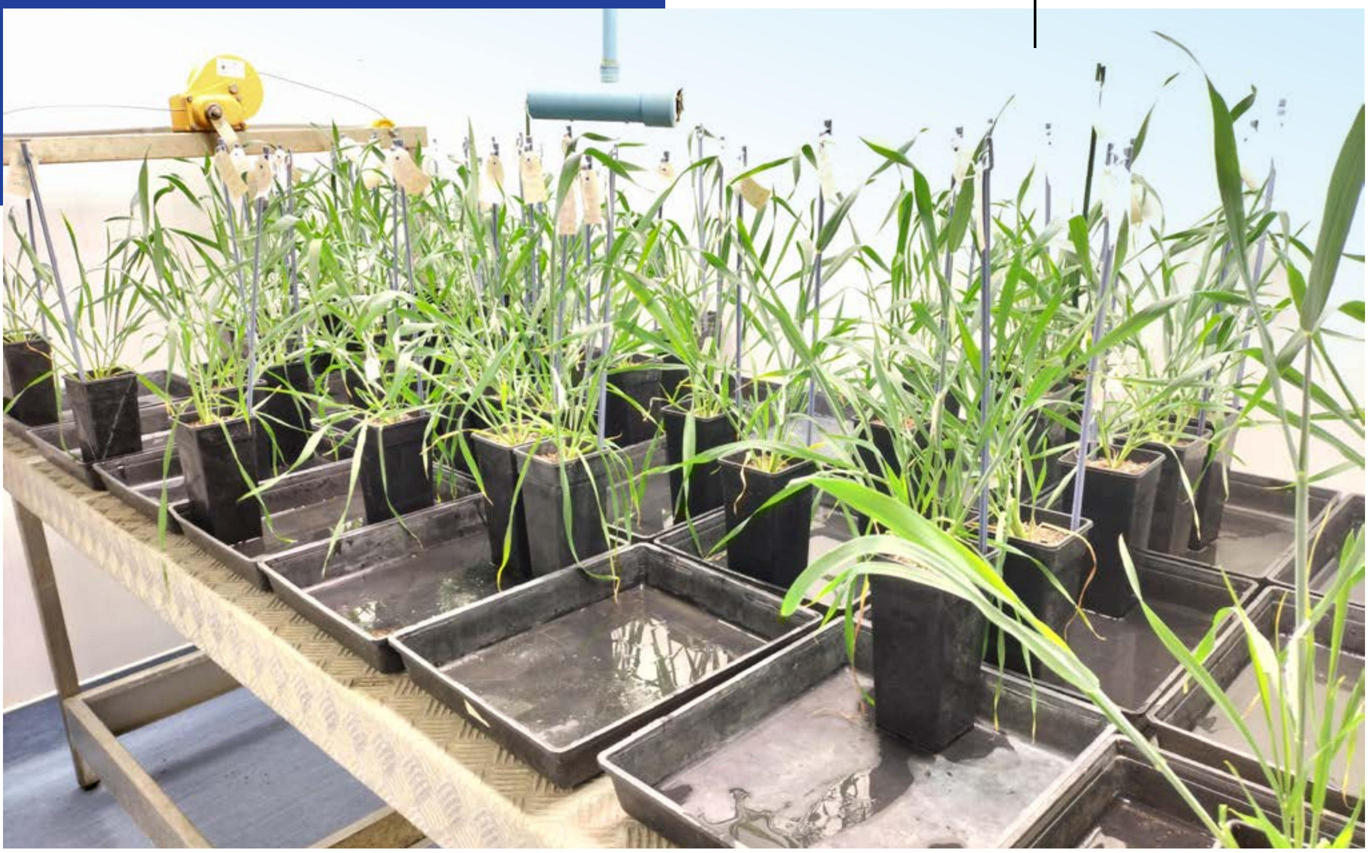
Collaborating organisation: [1]UWA

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 2022, the F_2 and F_3 progeny of crosses between heat-tolerant and heat-sensitive parents were exposed to heat waves during meiosis (early booting stage) in the growth room, and we supplied ample water to avoid drought stress. DNA samples from F_2 plants were submitted for whole-genome marker analysis. These experiments are the basis of QTL mapping and validation of candidate genes for heat stress tolerance during meiosis/sporogenesis. The QTL mapping analysis led to identification of key genomic regions for heat stress tolerance associated traits. Mukesh also used the Graduate Research Travel Award to visit heat stress breeding trials at Plant Breeding Institute, Narrabri (The University of Sydney) and gained valuable experiences for germplasm screening in field under portable heat chambers.

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

Screening wheat genotypes under UWA controlled environment rooms.



The sun shining through a wheat leaf in the field.

Transpirational leaf cooling effect did not contribute equally to biomass retention in wheat genotypes under high temperature

Project team: Dr Helen Bramley[1,2] (project leader; helbramley@gmail.com), Dr Chandima Ranawana[1,3], Adjunct Professor Jairo Palta[1,4], Associate Professor Katia Stefanova[1], Hackett Professor Kadambot Siddique[1]

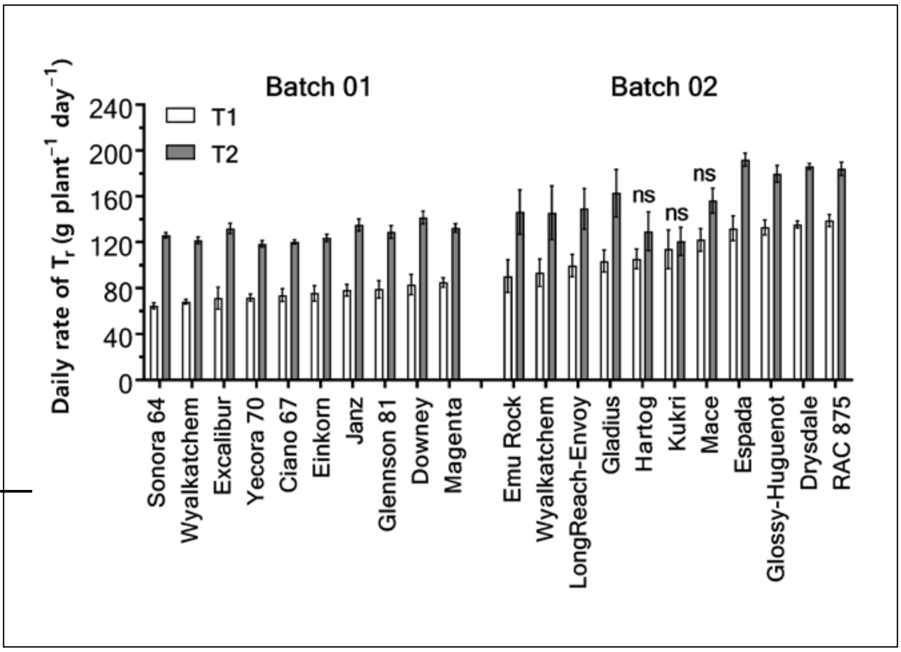
Collaborating organisations: [1]UWA; [2]The University of Sydney; [3]Uva Wellassa University, Sri Lanka; [4]CSIRO

High temperature and water deficit are the most critical yield-limiting environmental factors for wheat in rainfed environments. It is important to understand the heat avoidance mechanisms and their associations with leaf morpho-physiological traits that allow crops to stay cool and retain high biomass under warm and dry conditions.

We examined 20 morpho-physiologically diverse wheat genotypes under ambient and elevated temperatures (T_{air}) to investigate whether increased water use leads to high biomass retention due to increased leaf cooling. An experiment was conducted under well-watered conditions in two partially controlled glasshouses.

We measured plant transpiration (T_r), leaf temperature (T_{leaf}), vapor pressure deficit (VPD), and associated leaf morpho-physiological characteristics. High water use and leaf cooling increased biomass retention under high temperatures, but increased use did not always increase biomass retention. Some genotypes maintained biomass, irrespective of water use, possibly through mechanisms other than leaf cooling, indicating their adaptation under water shortage. Genotypic differences in leaf cooling capacity did not always correlate with T_r (VPD) response. In summary, the contribution of high water use or the leaf cooling effect on biomass retention under high temperature is genotype-dependent and possibly due to variations in leaf morpho-physiological traits. These findings are useful for breeding programs to develop climate resilient wheat cultivars.

This research is supported by UWA and an Australian Government Endeavour Postgraduate Scholarship.



Mean daily rate of transpiration (T_r) of 20 wheat genotypes in Batch 01 and 02 under ambient (T1) and high (T2) temperature regimes over the period of temperature treatment.

Impact of climate change on wheat grain composition and quality

Project team: Associate Professor Muhammad Farooq[1,2] (project leader; muhammad.farooq@uwa.edu.au), Dr Noreen Zahra[3], Dr Muhammad Bilal Hafeez[3], Abdul Wahid[3], Muna Hamed Al Masruri[2], Dr Aman Ullah[2], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Sultan Qaboos University, Oman; [3]University of Agriculture Faislabad, Pakistan

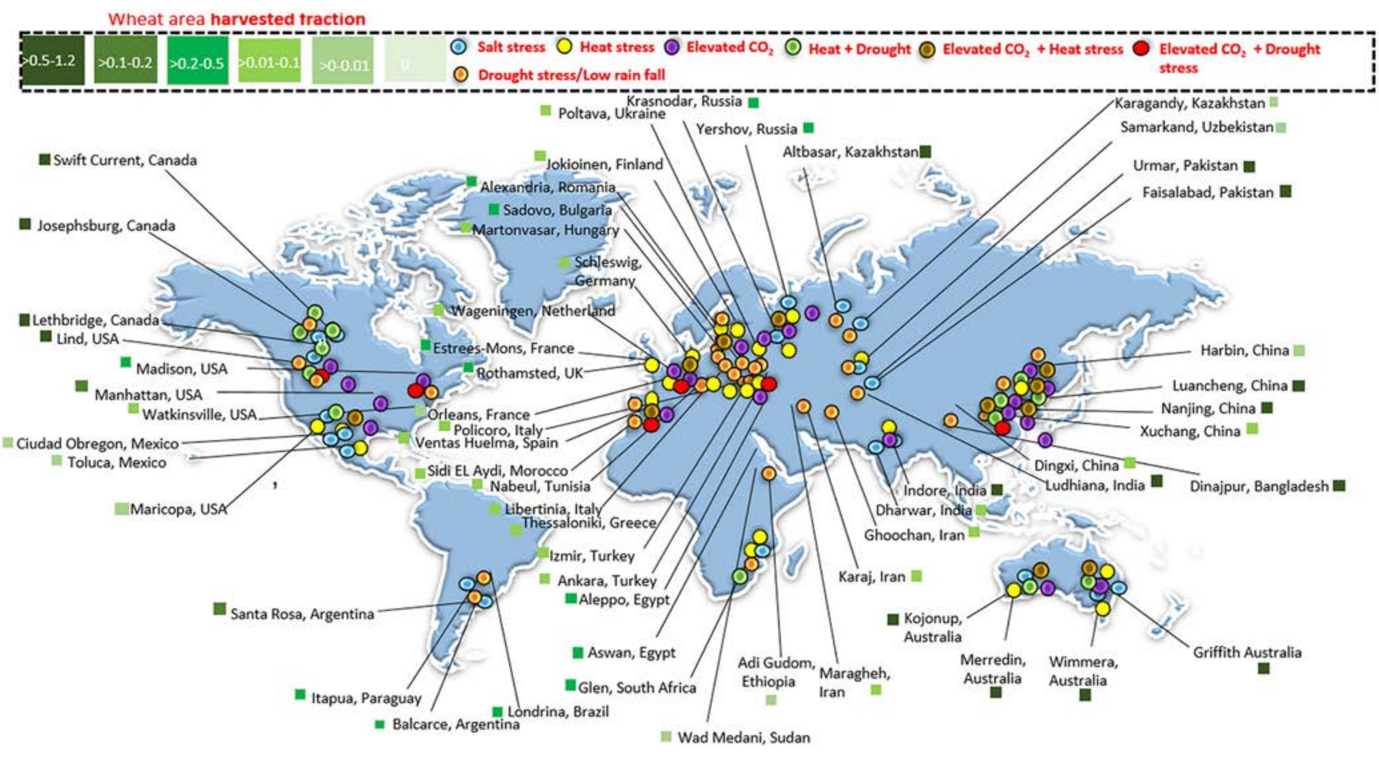
Greater research focus on the stress-induced alterations in wheat is essential to improve the sustainability and quality of crops during unpredictable climate shifts. This review paper, published in the *Journal of the Science of Food and Agriculture,* discussed the composition and quality of wheat grain during changes in climate and sketched a comprehensive atlas of grain nutrients and their chemical composition. It concluded that further genetic testing would likely uncover new avenues in stress physiology, which could pave the way for dealing with worldwide malnutrition and hunger by ensuring the healthy intake of staple foods.

Wheat (*Triticum aestivum* spp. aestivum and *Triticum turgidum* ssp. Durum) greatly contributes to global food security, serving as a staple food for approximately 40 per cent of the global population. However, wheat productivity is threatened by the unpredicted incidence of acute climatic events such as drought, heat, salinity, elevated CO_2 (eCO_2), heat and drought, eCO_2 and drought, and eCO_2 and heat stresses.

The research team determined that rapid climate shifts directly impacted wheat productivity and seriously affected principal grain components including starch, fibre, protein, amino acids, essential nutrients, grain weight and grain morphology. Climatic events showed differential regulation of protein and starch accumulation and mineral metabolism in wheat grains.

Climate change causes grain quality to deteriorate by interrupting the allocation of essential nutrients and photoassimilates. Unpredicted climate events continue to put pressure on crop productivity and quality, especially in developing countries. Maintaining wheat grain quality under climate change is critical for human nutrition, end-use functional quality, and commodity value.

This research is supported by His Majesty Trust Fund via Sultan Qaboos University.



A world map of climate change and the wheat harvest fraction of major wheat-cultivating countries.

A wheat field in north China. The Loess Plateau is China's largest rainfed wheat production area, with annual precipitation of 300–600mm.

Field-scale studies quantify limitations for wheat grain zinc biofortification in dryland areas

Project team: Associate Professor Chao Li[2], Zikang Guo[2], Xingshu Wang[2], Dr Yue Ma[2], Associate Professor Jinshan Liu[2] (project leader; jsliu@nwsuaf.edu.cn), Dr Mei Shi[2], Dr Di Zhang[3], Dr Sukhdev Malhi[4], Hackett Professor Kadambot Siddique[1], Dr Zhaohui Wang[2]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]Yangling Vocational & Technical College, China; [4]University of Alberta, Canada

Optimising of agronomic measures is an efficient way to improve crop zinc (Zn) nutrition and human dietary Zn intake. We collected field management, soil, and plant information from 78 fields in Shuiqing, 106 fields in Yongshou, and 120 fields in Qiujialing on China's Loess Plateau to explore limitations in wheat grain Zn and design alternative options to achieve the target grain Zn concentration (40 mg kg^{-1}).

The Shuiqing fields had an average grain yield of 5022 kg ha^{-1} and grain Zn concentration of 22.8 mg kg^{-1}, with no fields achieving the target grain Zn concentration due to phosphorus (P) fertiliser overuse (254 kg P_2O_5 ha^{-1}) and very low soil DTPA-Zn (0.23 mg kg^{-1}). Two Yongshou fields reached the target grain Zn concentration but had 52.3 per cent, 16.0 per cent, and 51.4 per cent lower average grain yield, P fertiliser rate, and soil Olsen-P, respectively, than other fields. The Qiujialing fields had an average grain Zn concentration of 34.8 mg kg^{-1}, with 18.3 per cent of fields ≥ 40 mg kg^{-1}, of which 91 per cent had soil DTPA-Zn ≥ 0.5 mg kg^{-1} and 45.2 per cent higher grain Zn uptake than other fields due to newly released wheat cultivars, low P fertiliser rates, low soil Olsen-P, and high soil mineral nitrogen.

In conclusion, a feasible framework for achieving the target grain Zn level would be using cultivars with high Zn uptake capacity, reducing P fertiliser use and soil Olsen-P, and improving soil available Zn in low Zn soils.

This research is supported by the China Agricultural Research System, and the National Key Research and Development Program of China.

Panicum species growing in a climate-controlled chamber.

Response of C3 and C4 grasses to elevated CO_2 and water deficit: A test of least-cost optimality theory

Project team: Dr Paul Drake[1] (project leader; paul.drake@uwa.edu.au), Professor Erik Veneklaas[1], Dr Hugo de Boer[2], Professor Karin Rebel[2]

Collaborating organisations: [1]UWA; [2]Utrecht University, Netherlands

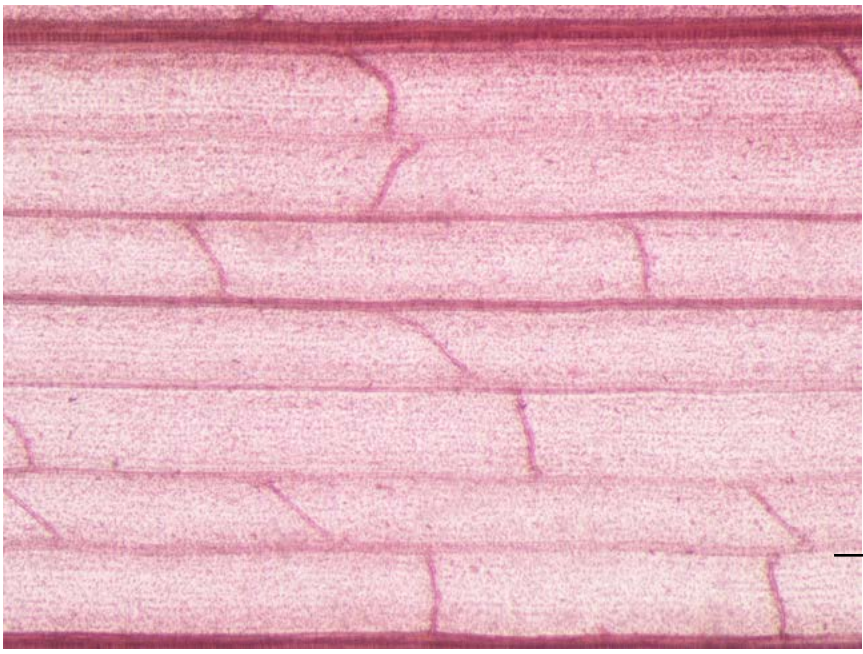
The C4 photosynthetic pathway occurs in approximately 3 per cent of terrestrial plant species but constitutes about 23 per cent of the Earth's primary productivity. The evolution of the C4 photosynthetic pathway coincided with a period of relatively low atmospheric CO_2 and a global climate dominated by dry, seasonally variable landscapes in the subtropics and temperate zones. The advantage of the C4 pathway under these conditions is clear: the CO_2-concentrating mechanism supresses photorespiration and increases water-use efficiency, thereby enhancing photosynthesis when CO_2 and water are scarce.

As the Earth enters a period of increased climatic instability owing to the release of greenhouse gasses by humans, there is consensus that atmospheric CO_2 will increase beyond the concentrations at which the C4 pathway evolved and many regions currently supporting C4 species will experience reduced rainfall or more frequent droughts.

In this research, we tested for morphological and physiological adaptation of closely related C3 and C4 grasses of agricultural significance (*Panicum* species) when grown at an elevated atmospheric CO_2 concentration and under a controlled water deficit. We develop further insights into the adaptation of the species to these conditions using a model based on the least-cost theory of photosynthesis. The least-cost hypothesis is centred on the idea that plants will adjust to their environment to minimise the carbon costs of photosynthesis.

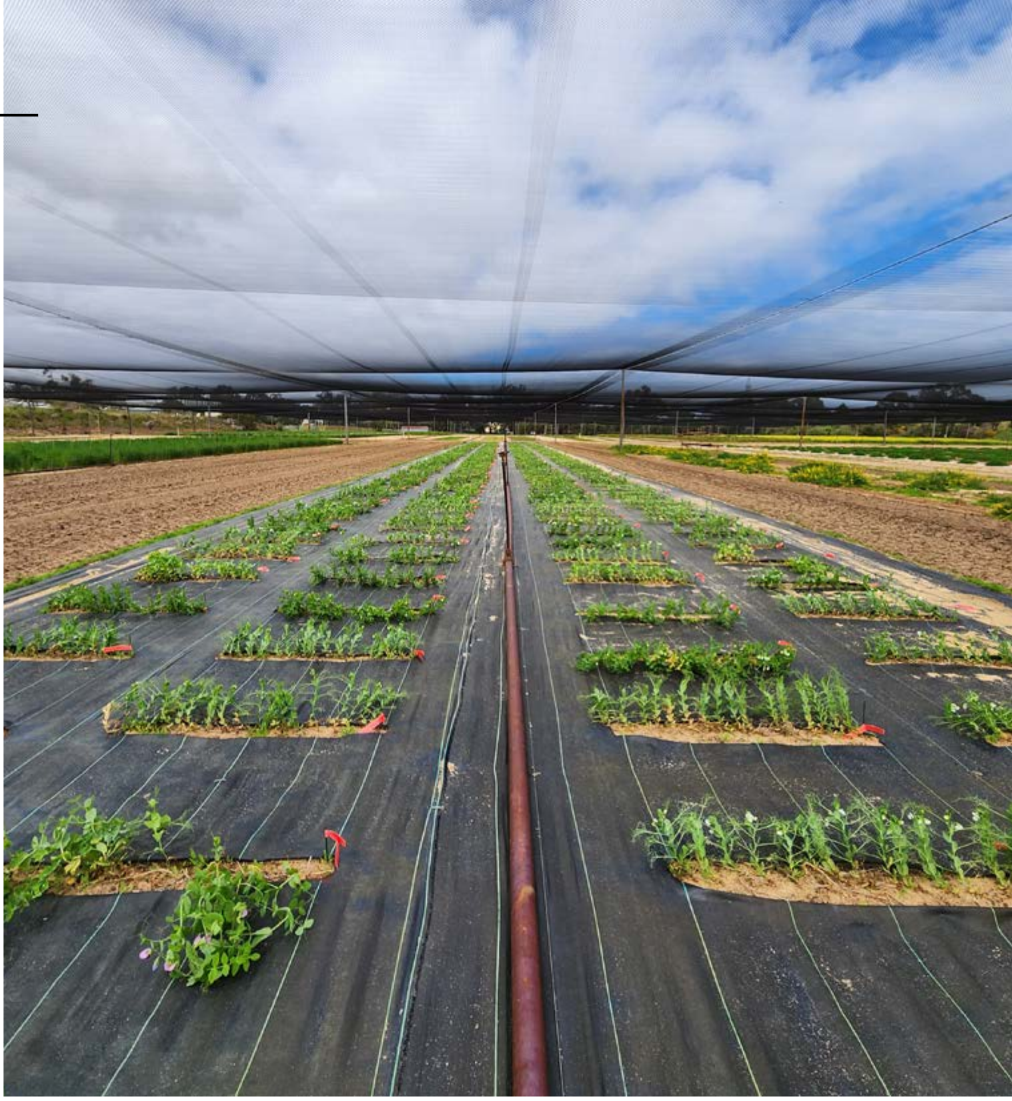
Consistent with least-cost theory, provisional results suggest greater photosynthetic and morphological adaptation to elevated CO_2 and water deficit in C3 grasses, while C4 grasses remain more water use efficient across growth conditions. These results will support improved land surface models for the prediction of climate change impacts and provide important insights in traits that may enhance productivity and water-use efficiency of key crop and pasture species.

This research is supported by UWA and the LEMONTREE project. The project is part of the VESRI Virtual Earth System Research Institute – Schmidt Futures, funded by Eric and Wendy Schmidt.



Panicum leaf venation with a distinct hierarchy of large and intermediate longitudinal veins and small connecting transverse veins.

A drone photo from the NPZ canola breeding project field trials in Boddington, Western Australia.



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 organisation: [1]UWA; Norddeutsche Pflanzenzucht Hans-Georg Lembke KG (NPZ)

NPZ Lembke in Germany has funded projects at UWA since 2000 for pre-breeding of spring canola and field peas. As a result, 37 new canola varieties have been released since 2003 which have added significant value to Australian canola growers. In addition, this long-term research partnership has resulted in new rapid-breeding methods for self-pollinating crops based on UWA research in canola and field peas.

In 2022, the canola pre-breeding project published the results of a 10-year global research project with NPZ in Germany and its partner DL Seeds in Canada which revealed high rates of genetic gain for grain yield, seed oil and protein, and blackleg disease resistance in a global canola breeding population (Cowling WA et al. [2023] *Plants*). With optimal contributions selection, the population also retained high genetic diversity which provided confidence that the breeding program will achieve long-term genetic gain.

NPZ continued to fund a UWA-based pea project with PhD student Felipe Castro-Urrea to rapidly improve field peas for stem strength, black spot disease resistance, and grain yield. Felipe is using whole-genome markers in the pea breeding population to discover important genetic correlations between field and glasshouse traits which will help accelerate breeding for low heritability and difficult to measure traits.

New methods of analysis developed in this pea project include multivariate analysis with pedigree and genomic relationship information, and optimal contributions selection based on an economic index (Castro-Urrea FA et al. [2023] *Plants*).

This research is supported by UWA and NPZ Lembke.

Field pea breeding program field trial at UWA Shenton Park Field Station in 2022.

Dr Sheng Chen introducing the progress of the GRDC-funded canola heat tolerance project at the UWA Shenton Park Field Station 2022 Open Day.

Improving canola heat tolerance – A coordinated multidisciplinary approach

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

Collaborating organisations: [1]UWA; [2]NSW DPI; [3]SAGI West; [4]Kalyx, WA; [5]Irrigated Cropping Council, 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 UWA, NSW Department of Primary Industry (NSW DPI) and Statistics for the Australian Grains Industry (SAGI). The research involves controlled-environment and field-based experiments to discover and validate genes for canola heat stress tolerance.

Previous trial data from the Heat Screening Facility at UWA's Field Station at Shenton Park revealed some genotypes with good tolerance to heat stress or capacity to recover after heat stress. These putative heat tolerant genotypes, together with other lines, were re-evaluated in 2022 (total 100) under the same heat stress regime. The heat stress tolerance was assessed by the percentage yield change (PC) in seed production between the heat stress and control treatments as well as a stress tolerance index (STI). 42 lines were identified with outstanding PC and STI scores, with the top eight lines consistently yielding well in both early and late sowing conditions.

A total of 324 genotypes phenotyped for heat tolerance at UWA were subjected to whole genome SNP-based genomic analysis. 162 significant marker-trait associations (MTAs) were identified across the heat tolerance as measured by the PC or STI of 8 yield-related traits, among which 62 MTAs showed more than 5% phenotypic variance explained. 41 QTL regions were identified over the whole genome and each QTL contributed to the heat tolerance based on one or more yield-related traits. 334 candidate genes are potentially related to heat stress tolerance. Among them, 125 genes are related to zinc finger and receptor kinase, 127 genes related to membrane protein, cell division/chromosome partitioning and stress response, etc. and 27 genes related to heat-shock proteins. These genes, once their functions are confirmed, could be used for improving heat tolerance in canola breeding programs.

In 2022, a field experiment was successfully completed using potable heat chambers at NSW DPI in Wagga Wagga. Sixteen genotypes were assessed in a replicated experiment in 6m long, three-row plots for heat tolerance at early flowering. There was significant effect of heat stress on main stem seed yield due to reduction in seed number. Plot yield analysis showed several lines had good mean productivity and intermediate in percentage change in plot yield, so could be candidates for heat tolerance.

In 2022, 48 genotypes with different heat stress tolerance and/or recovery capability after heat stress were successfully validated with 3 sowings and 2 replicates at Dongara WA and Leeton NSW. The field trial at Kerang VIC, however, were written off due to severe flooding issues. In 2023, the same set of 48 genotypes is under re-validation at Dongara WA, Kerang VIC, Leeton NSW, Narrabri NSW and Condobolin NSW.

At the end of this project, we will confirm the value of heat stress tolerant canola genotypes in multi-environment field trials, and identify 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.

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

Canola (*Brassica napusL.*) growing tall in a field.

Chloe Rout was a finalist in the Young Professionals in Agriculture Forum.

Flowering hybrid canola in the field.

Exploring the ability of hybrid canola (*Brassica napus L.*) to compensate for poor establishment

Project team: Chloe Rout[1] (project leader; chloe.rout223@gmail.com), Professor Ken Flower[1], Associate Professor Matthias Leopold[1], Dr Andrew Wherrett[2]

Collaborating organisations: [1]UWA; [2]Living Farm

Poor canola (*Brassica napus L.*) establishment is a challenge for Australian producers, and the causes are not well understood. To date there has been limited research aimed at supporting grower decision-making on whether to reseed hybrid canola crops with poor establishment, using cheaper open pollinated canola.

This field study was conducted in the 2022 growing season near York in Western Australia. The season had above average rainfall, with 382 mm over the growing season. The study had two aims, with the first to investigate the compensatory ability of hybrid canola at target densities of 5, 10, 15, 20 and 40 plants/m^2. The second was to determine if reseeding, with open pollinated canola, was beneficial in simulated poor establishment conditions where hybrid canola densities were 5 and 10 plants/m^2.

The hypotheses were that the compensatory ability of canola was expected to increase as plant density declined. Secondly, reseeding hybrid canola with open pollinated canola was only expected to be beneficial when hybrid plant establishment was less than 50 per cent of the recommended optimum (~25-40 plants/m^2). To quantify the compensatory ability of hybrid canola and to assess if reseeding is beneficial, the architecture of the canola plants (branching and podding pattern), canopy cover and yield was measured. The total number of pods per plant (particularly secondary and tertiary located pods) and dry matter weight was observed to increase in response to a decline in plant density. Therefore, the compensatory ability of hybrid canola increased in response to poor establishment, supporting the first hypothesis.

Interestingly, the number of pods per unit area and grain yield exhibited the opposite trend increasing with a rise in plant density. However, the hybrid canola was able to achieve up to 95 per cent of the optimal yield if plant density was above 15 plants/m^2 and therefore adequately compensated for poor establishment. Unexpectedly, reseeding hybrid canola with open pollinated canola adversely impacted yield suggesting that it was not beneficial to reseed. Overall, the results from this study suggest that, in a season with above average rainfall, producers in this area may be able to avoid the timely process of resowing and still achieve adequate yields due to the compensatory ability of canola.

This research is supported by UWA, Living Farm, and the Mary Janet Lindsay of Yanchep Memorial Scholarship.

Investigating salinity tolerance in mungbean at the vegetative and reproductive stages using Genome-Wide Association Studies and Genomic Selection

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

Collaborating organisations: [1]UWA; [2]DPIRD; [3]International Center for Tropical Agriculture CIAT-Asia; ACIAR; World Vegetable Center

Mungbean is one of the important grain legume crops widely grown in the rice-based farming systems of South and Southeast Asia. Salinity stress has emerged as a severe threat to crop production under all 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. Dissection, identification and pyramiding of salinity tolerance associated traits can be applied in breeding to develop salinity tolerant mungbean 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.

This study explored the phenotypic and genetic variation in mungbean mini-core accessions for salinity tolerance at the early vegetative, late vegetative and reproductive stages. Firstly, 292 mungbean mini-core accessions were grown at 0 mM NaCl (non-saline control) and 75 mM 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 the early vegetative stages (30 days after sowing) and reproductive stages. Large phenotypic variation was observed in all observed 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.

Using Illumina resequencing and DArT sequencing SNP markers data on the mini-core accessions, genome wide association studies (GWAS) and genomic selection are being undertaken to understand the genetic basis of salinity tolerance in mungbean. The increased understanding of morpho-physiology and genetics of salt tolerance in mungbean will guide legume breeders in the improvement of salt tolerance and climate resilience of legumes.

This research is supported by UWA, ACIAR and the John Allwright Fellowship Award.

Photos clockwise from left:
PhD candidate Md Shahin Iqbal screening mungbean for salinity tolerance in a UWA glasshouse.
Phenotyping mungbean mini-core collection for salinity tolerance.
Contrasting mungbean genotypes grown in 75 mM NaCl.

Assessing the heat sensitivity of Urdbean (*Vigna mungo* L. Hepper) genotypes involving physiological, reproductive and yield traits under field and controlled environment

Project team: Shikha Chaudhary[2], Dr Uday Chand Jha[3] (project leader; uday_gene@yahoo.co.in), Dr Pronob Paul[4], Dr P.V Vara Prasad[5], Professor Kamal Dev Sharma[6], Professor Sanjeev Kumar[7], Dr Debjyoti Sen Gupta[3], Dr Parul Sharma[8], Dr Sarvjeet Singh[8], Hackett Professor Kadambot Siddique[1], Professor Harsh Nayyar[2]

Collaborating organisations: [1]UWA; [2]Panjab University, India; [3]ICAR-Indian Institute of Pulses Research, India; [4]International Rice Research Institute, India; [5]Kansas State University, US; [6]Choudhary Sarwan Kumar Himachal Pradesh Agricultural University, India; [7]Central University of Punjab, India; [8]Punjab Agricultural University, India

The rising temperatures are seriously impacting the food crops, including urdbean; hence efforts are needed to identify the sources of heat tolerance in such crops to ensure global food security. In the present study, urdbean genotypes were evaluated for heat tolerance under natural outdoor for two consecutive years (2018, 2019) and subsequently in the controlled environment of the growth chamber to identify high temperature tolerant lines. The genotypes were assessed involving few physiological traits (membrane damage, chlorophyll, photosynthetic efficiency, stomatal conductance, lipid peroxidation), reproductive traits (pollen germination per cent and pollen viability per cent) and yield related traits (total number of pods plant^{-1}, total seeds plant^{-1}, single seed weight and seed yield plant^{-1}).

Based upon these tested traits, PantU31, Mash114, UTTARA and IPU18-04 genotypes were identified as promising genotypes for both years under heat stress condition. Further confirming heat tolerance, all these four tolerant and four sensitive genotypes were tested under controlled environment under growth chamber condition. All these four genotypes PantU31, Mash114, UTTARA and IPU18-04 showed high chlorophyll content, photosynthetic efficiency, stomatal conductance, leaf area, pods plant^{-1}, total seeds plant-1 and low reduction in pollen germination per cent and pollen viability under stress heat stress condition. Moreover, yield and yield related traits viz., pods plant^{-1}, seeds plant^{-1}, single seed weight and seed yield plant^{-1} showed very strong positive correlation with pollen germination and pollen viability except electrolyte leakage and malondialdehyde content. Thus, these genotypes could be potentially used as donors for transferring heat tolerance trait to the elite yet heat-sensitive urdbean cultivars.

Urdbean plants showing various distinctive impacts in the reproductive phase when raised under control and heat stress environment.

This research is supported by UWA and the Council of Scientific & Industrial Research.

Improved seed yield and phosphorus accumulation in soybean are associated with the enhanced root exudates in south-west China

Project team: Dr Hong-Lan Zhang[2], Dr Nian Liang[2], Associate Professor Rui Dong[2], Dr Chang-An Liu[3], Chun-Ling Hao[2], Hackett Professor Kadambot Siddique[1], Adjunct Professor Jin He[2] (project leader; hejin0811@163.com)

Collaborating organisations: [1]UWA; [2]Guizhou University, China; [3]Chinese Academy of Sciences, China

Shoot traits related to soybean yield improvement are well characterised, but little is known about changes in root traits and their contribution to yield improvements under different P levels. Field experiments conducted in 2018 and 2019 (two sites each year under 0 (P0) and 35 (P35) kg P ha^{-1}) compared root morphology, P and N accumulation and uptake efficiencies, and seed yield of 12 soybean cultivars released from 1995 to 2016. A supplementary pot experiment with the same soybean cultivars compared root exudates and arbuscular mycorrhizal (AM) colonisation rates under 0 and 60 mg kg−1 P supply.

The four site × year field combinations revealed significant genetic gain from soybean breeding for seed yield under P35 (2.1–2.3 per cent) and P0 (1.8–2.0 per cent), respectively. Soybean breeding significantly increased P and N accumulation, which positively correlated with seed yield under P35 and P0. Root length, specific root length, and carboxylate exudation were associated with P and N accumulation and uptake efficiencies, but only root exudates significantly improved with year of cultivar release. The AM colonisation rate increased under low soil availability but did not change with year of release.

Our results suggest that indirect selection of root traits, such as root exudates, during soybean breeding could improve P and N accumulation and uptake efficiencies to improve seed yield.

This research is supported by the National Natural Science Foundation of China, Guizhou Science and Technology Support Program Project, and Guizhou Provincial Biology First-Class Discipline Construction Project.

A row of soybean plants growing in the field.

Green pods on a healthy soybean plant.

Interaction of rhizobia with native AM fungi shaped biochar effect on soybean growth

Project team: Minglong Liu[1,2], Xianlin Ke[2], Professor Stephen Joseph[2,3], Hackett Professor Kadambot Siddique[1], Professor Genxing Pan[2], Dr Zakaria Solaiman[1] (project leader; zakaria.solaiman@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]Nanjing Agricultural University, China; [3]University of New South Wales

While biochar amendment is widely recommended as an excellent agricultural management practice, the biochar effect on the productivity of legume crops with symbiotic microorganisms has been poorly elucidated. Hence, a pot experiment was conducted by growing soybean with or without commercial rhizobia inoculation in an arbuscular mycorrhizal (AM) fungi rich sandy soil amended with wheat straw biochar produced respectively at 350°C, 450°C, and 550°C.

We tested the effect of biochar on soybean–rhizobia symbiosis and its impact on plant growth, leaf gas exchange and mycorrhizal colonisation. In brief, rhizobia inoculation, without biochar, increased net photosynthetic rate by 81 per cent and plant total biomass by 44 per cent compared to no inoculation (the control). Without inoculation, amendment of low-temperature biochar (350°C) resulted in higher (by 51 per cent) plant biomass than high-temperature (550°C) biochar. With rhizobia inoculation, low-temperature biochar decreased plant biomass by 9.3 per cent compared to high-temperature biochar. Further, soybean with rhizobia under high-temperature biochar decreased plant biomass by 17 per cent compared to rhizobia inoculation only but increased by 19 per cent compared to the control. Soybean leaf gas exchange capacity and root morphological traits were consistent with plant biomass but symbiotic activity showed small differences among all the treatments.

Overall, N-fixing rhizobia could alter the biochar effect on soybean in soil rich in indigenous AM fungi, depending on the pyrolysis temperature of the biochar used. Low-temperature biochar stimulated soybean growth greater than high-temperature biochar, while rhizobia shifted biochar's positive effect.

This research is supported by UWA, Troforte Innovations Pty Ltd and the Chinese Scholarship Council.

Straw mulching for enhanced water use efficiency and economic returns from soybean fields in the Loess Plateau China

Project team: Professor Feng Li[2] (project leader; lifeng@rcees.ac.cn), Guohong Zhang[3], Dr Juan Chen[3], Yali Song[2], Zhiguang Geng[2], Kefu Li[2], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Qingyang Academy of Agricultural Sciences, China; [3]Gansu Academy of Agricultural Sciences, China

Water shortages threaten agricultural sustainability in the semi-arid areas of the Loess Plateau. Judicious mulching management can improve water conservation practices to alleviate this issue while increasing crop productivity. We investigated the effect of straw strip mulching and film mulching on soil water consumption, temperature, growth, grain yield, and economic income of soybean [*Glycine max* (Linn.) Merr.] from 2017 to 2018 in Qingyang on the semi-arid Loess Plateau in China using four treatments:

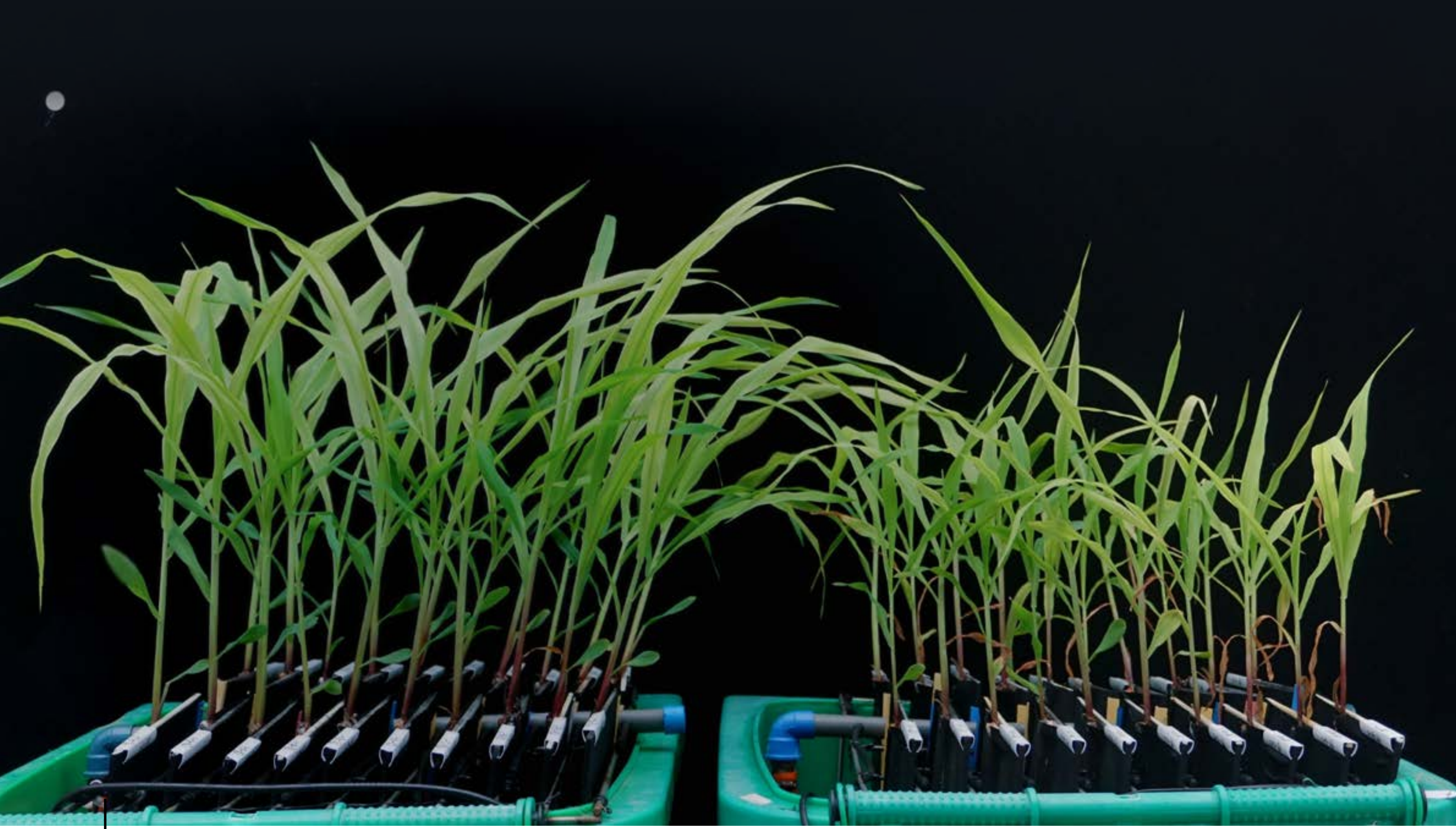
a) Alternating ridges and furrows with ridges mulched with white polyethylene film (PMP),
b) Alternating flat and bare land with only the plat mulched by white polyethylene film (PMF),
c) Alternating strips mulched with maize (Zea mays L.) straw (SM), and
d) Traditional land planting without mulching (CK). The mulching treatments (PMP, PMF, and SM) increased soil water consumption and soil water use efficiency.

The SM, PMF, and PMP treatments had 12.3-12.5, 16.8-22.1, and 23.2-24.2 mm higher soil water consumption (0-120 cm depth) than CK, most of which occurred in the 60-120 cm soil layer. Compared with CK, PMP and PMF significantly increased soil temperature by 1.30-1.31 °C and 0.76-1.00°C, soybean grain yield by 38.6-39.0 per cent and 38.8-44.2 per cent, and water use efficiency (WUE) by 27.7-32.8 per cent and 30.8-37.5 per cent, respectively, while SM significantly decreased soil temperature by 0.96-1.15°C, and increased grain yield by 21.8-25.4 per cent and WUE by 16.9-21.9 per cent. PMP and PMF did not significantly change soil water consumption, WUE, or grain yield. The SM treatment increased net income by 501.3-691.7 and 1914.5-2244.9 CNY ha-1 relative to PMP and CK, respectively, but PMF and SM did not significantly differ.

Straw mulching improved soil moisture, soil water content, and WUE and maintained the economic returns of soybean cultivation compared to plastic film mulching. Strip straw mulching could be used as an environmentally friendly cultivation technology for soybean production in semi-arid regions of the Loess Plateau in China. Therefore, the SM system could help increase grain yields and economic returns in dryland soybean production, avoiding the adverse effects of the increasingly popular plastic mulching approach.

This research is supported by the China Agriculture Research System, and the Science and Technology in Development Planning of Lanzhou.

The two main methods of straw returning for sustaining crop productivity and soil fertility in China involve incorporating straw into the top soil or mulching straw on the soil surface.



Growth of 20 maize genotypes cultivated for 39 days after transfer in a semi-hydroponic system with no Cd addition (CK, left) or with 20 μmol/L CdCl2 (right).

Maize genotypes with contrasting root systems differed in the tolerance to cadmium toxicity

Project team: Dr Yinglong Chen[1] (project leader; yinglong.chen@uwa.edu.au), Yujie Wu[2], Tingting An[2], Yamin Gao[2], Qiqiang Kuang[2], Shuo Liu[2], Liyan Liang[2], Professor Bingcheng Xu[2], Professor Suiqi Zhang[2], Professor Xiping Deng[2]

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

Cadmium (Cd) contamination in farmland is a serious environmental and safety issue affecting plant growth, crop productivity, and human health. This study assessed genotypic variation in root morphology, Cd accumulations and Cd tolerance under moderate Cd stress (20 μmol/L $CdCl_2$) among 20 maize genotypes with contrasting root systems (selected from Qiao et al. [2019] Plant Soil) 39 days after transplanting (V6, six-leaf stage) using the semi-hydroponic phenotyping platform (Chen et al. [2011] Functional Plant Biology).

This study revealed that maize genotypes varied significantly in response to moderate Cd stress. Cd-tolerant genotypes optimised root morphology and Cd accumulation and distribution in plant tissues. Cd stress significantly inhibited plant growth across all genotypes. Genotypic variation in response to Cd toxicity was apparent: shoot dry weight varied from 0.13 (genotype NS2020) to 0.35 g/plant (Dongke301) with deductions up to 63 per cent compared with non-Cd treatment (CK). Root dry weight of 20 genotypes ranged from 0.06 (NS2020) to 0.18 g/plant (Dongke301) with a deduction up to 56 per cent. Root length ranged from 2.21 (NS590b) to 9.22 m/plant (Dongke301) with a maximal decline of 76 per cent. Cd-treated genotypes generally had thicker roots and average diameter increased by 34 per cent compared with CK. Genotypes had up to 3.25 and 3.50 times differences in shoot and root Cd concentrations, respectively. Principal component and cluster analyses assigned the 20 genotypes into Cd-tolerant (five genotypes) and Cd-sensitive (15 genotypes) groups.

This study could assist in the selection and breeding of new cultivars with improved adaptation to Cd-contaminated soil for food and feed or land remediation purposes.

This research is supported by the National Natural Science Foundation of China and Australian Research Council.

Effect of silicon on morpho-physiological attributes, yield and cadmium accumulation in two maize genotypes with contrasting root system size and health risk

Project team: Dr Yinglong Chen[1] (project leader; yinglong.chen@uwa.edu.au), Tingting An[2], Yamin Gao[2], Qiqiang Kuang[2], Yujie Wu[2], Professor Yi Zhang[2], Professor Bingcheng Xu[2], Dr Qamar uz Zaman[3]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]The University of Lahore, Pakistan

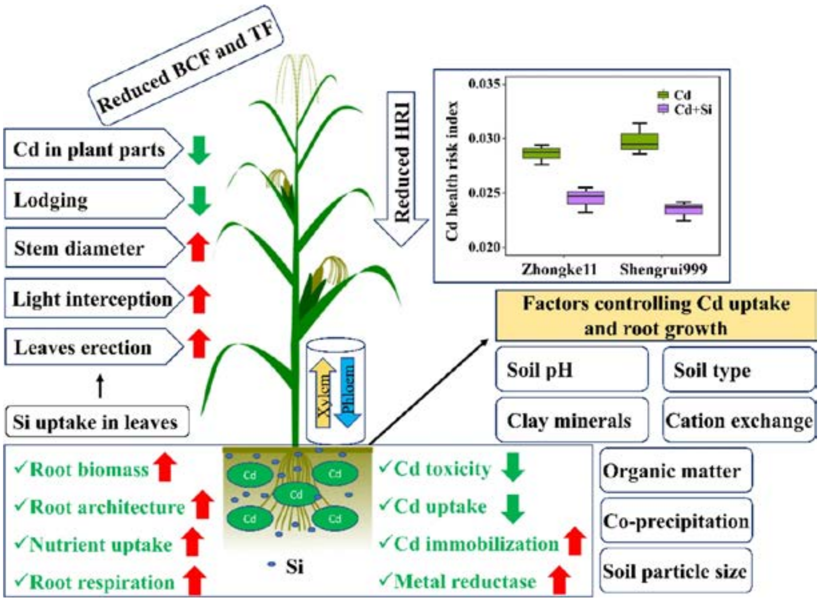
Silicon (Si) was reported to have some alleviative effects of plants under abiotic stress including cadmium (Cd) toxicity. However, whether Si alleviates Cd toxicity in maize genotypes with contrasting root system size are unknown.

A pot experiment investigated the effects of Si application on plant growth, Cd uptake and transportation under Cd stress (20 mg/kg soil) at the silking and maturity stages of two maize genotypes Zhongke11 (deep-rooted) and Shengrui999 (shallow-rooted). The study showed that application of Si significantly increased root dry weight, plant height and root length. Root volume and average root diameter were significantly positively correlated with root Cd concentration, bioaccumulation and translocation factor, respectively, of two maize genotypes at the silking stage. Addition of Si significantly increased Cd concentration, content, bioconcentration and translocation factor in roots of Zhongke11, but reduced the values of these parameters in Shengrui999 at both growth stages. Adding Si to Cd treatment significantly reduced Cd concentration in grains (by 14.4 per cent in Zhongke11 and 21.4 per cent in Shengrui999. Grain yield was significantly negatively correlated with root Cd accumulation. Moreover, addition of Si significantly reduced Cd daily intake and health risk index in maize.

This study together with follow-up experiments demonstrated the role of Si in reducing health risk through eliminating Cd accumulation in maize shoot and grain, and in alleviating Cd stress with more profound effects in the shallow rooted genotype compared to deep rooted genotype.

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

Maize growing in an open field.



Schematic model of the effects of silicon (Si) in soil, root, stem, leaf and grain under cadmium (Cd) stress at the maturity stage.

Assessing phosphorus efficiency and tolerance in maize genotypes with contrasting root systems at the early growth stage

Project team: Dr Yinglong Chen[1] (project leader; yinglong.chen@uwa.edu.au), Liyan Liang[2], Tingting An[2], Shuo Liu[2], Yamin Gao[2], Professor Bingcheng Xu[2], Professor Suiqi Zhang[2], Professor Xiping Deng[2], Professor Min Yu[3], Hackett Kadambot Siddique[1], Professor Nanthi Bolan[1]

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

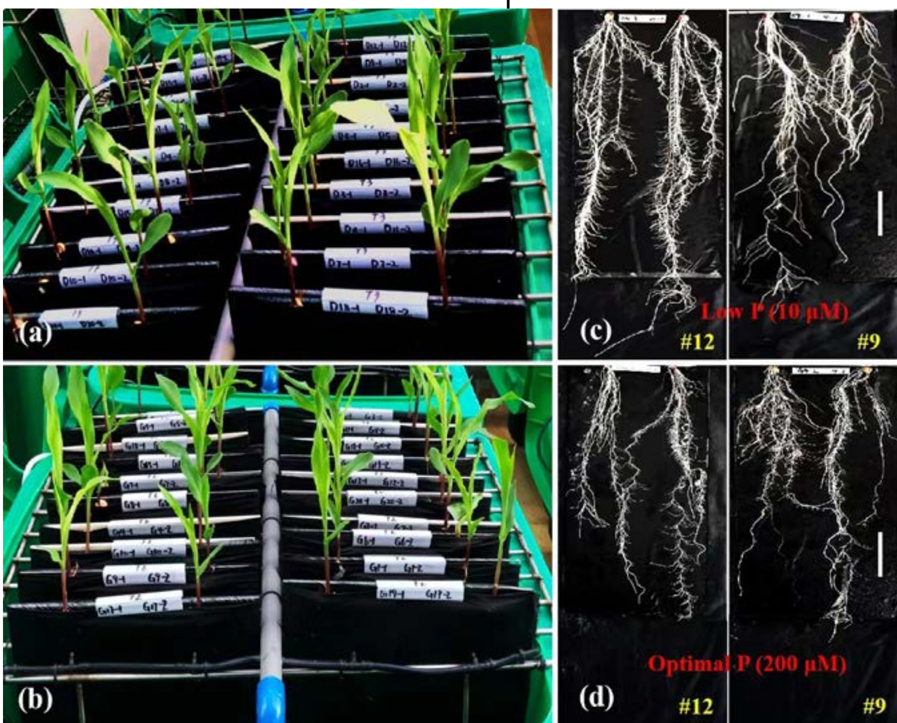
Development of an evaluation tool to determine genotypic variation in phosphorus (P) utilisation efficiency is essential to ensure crop productivity and farmers' income under low P environments. This study aimed to develop an evaluation tool to determine genotypic variation in low-P tolerance and P use efficiency under low P environments.

Root response and P efficiency traits in 20 maize genotypes with contrasting root systems (selected from Qiao et al. 2019 Plant Soil) were assessed 32 days after transplanting into the semi-hydroponic root phenotyping system (Chen et al. 2011 Functional Plant Biology) under low P (10 μM) or optimal P (200 μM) supply. Results showed that low P supply increased root-to-shoot biomass ratio by 48.7 per cent (shoot dry weight decreased by 20 per cent and root dry weight increased by 20.6 per cent per cent). Low P supply increased total root length by 17.8 per cent but decreased primary root depth, with no significant change in lateral root number across all genotypes. Low P stress enhanced P utilisation efficiency. Based on genotypic variation and correlations among the 17 measured plant traits in response to low P stress, nine traits were converted to low-P tolerance coefficients (LPTC), compressed by principal component analysis. The three principal component scores were extracted for hierarchical cluster analysis and classified the 20 genotypes into three groups with different P efficiency, including two P-efficient genotypes and nine P-inefficient genotypes.

The study demonstrated that maize genotypes with contrasting root system architecture differed in response to low P stress. The P-efficient genotypes with higher LPTC values better adapted to low P environments by adjusting root architecture and re-distributing P and biomass in plant organs. The systematic cluster analysis using selected traits and their LPTC values can be used as an evaluation tool in assessing P efficiency among the genotypes.

This research is supported by the National Natural Science Foundation of China and Australian Research Council.

Maize plants grown in the semi-hydroponic phenotyping systems 15 days after transplanting under low P (10 μM, A) and optimal P (200 μM, B), and example root images of maize genotypes (#12 and #9) under low P (10 μM, C) and optimal P (200 μM, D) photographed 32 DAT. White bar = 10 cm (C and D).



Testing coordination and optimality of stomatal conductance and photosynthetic biochemistry of six common crop species acclimating to elevated CO_2

Measuring leaf gas exchange on Borlotti bean.

Project team: Professor Hugo de Boer[2], Professor Karin Rebel[2], Dr Paul Drake[1], Professor Erik Veneklaas[1] (project leader; erik.veneklaas@uwa.edu.au), Jan Lankhorst[1,2], Astrid Odé[1,2]

Collaborating organisations: [1]UWA; [2]Utrecht University, Netherlands

Elevated atmospheric CO_2 tends to increase photosynthetic rates, but a simultaneous decrease in stomatal opening partly cancels the positive effect. Plants regulate their gas exchange by dynamically adjusting their stomata on a short-term time scale (opening and closing) and long-term time scale (stomatal size and density), which also influences photosynthesis. The operational stomatal conductance (Gop) represents the opening state of the stomata during typical growth conditions. The anatomical maximum stomatal conductance (Gsmax) is defined by the maximum stomatal aperture, stomatal density, and pore depth. Plants generally operate at the conservative Gop:Gsmax ratio of ~0.25, which means that they utilise only a fraction of their anatomical potential. In this study, we investigate if this ratio can be explained by optimality rules, and if it holds when plants grow at elevated CO_2.

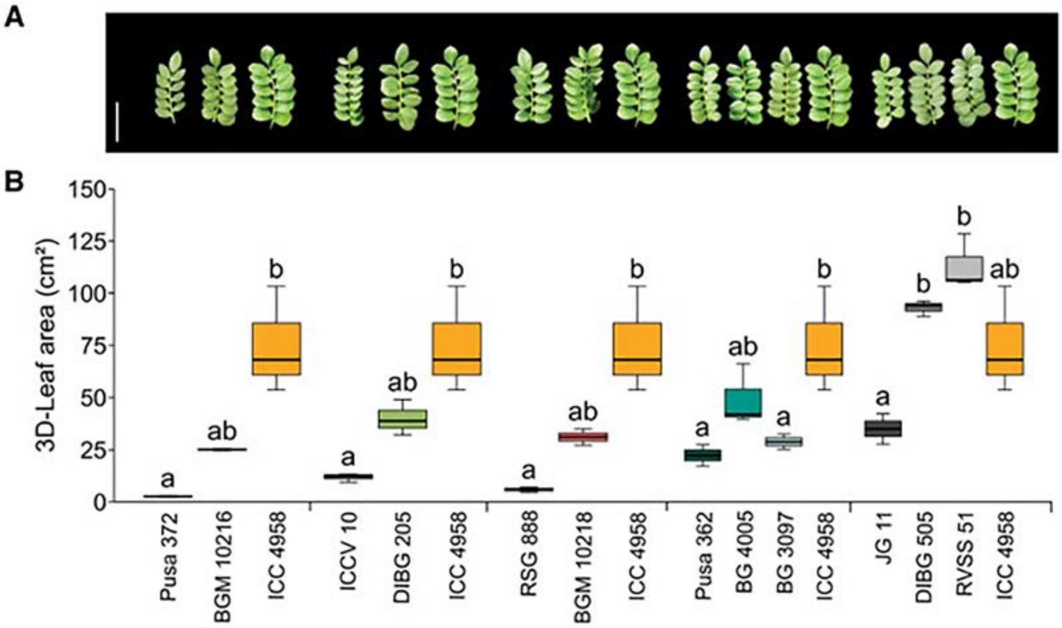
We grew six common crop species in ambient (400ppm) and elevated (1000ppm) CO_2 growth chambers. Species included dicots and monocots (one C3 and one C4 photosynthesis species), enabling an assessment of adaptation in species with different photosynthetic mechanisms and stomatal morphologies.

Preliminary results show that exposure to elevated CO_2 led to an increase in photosynthetic rate but a decline in photosynthetic capacity, Gop and Gsmax, as expected. The Gop:Gsmax ratio of the elevated atmospheric CO_2 treatment was slightly higher than at ambient levels. When all physiological and morphological analyses are completed, we will have a better understanding of the coordinated changes in stomatal morphology and behaviour, as well as photosynthetic biochemistry under elevated CO_2 for some of the most common grain crop species in the world. This will benefit the ability of global land surface models to predict responses to elevated CO_2 and changed climates, and can also inform breeding and agronomy of crops, supporting food security.

This research is supported by UWA and the LEMONTREE project. This project is part of the VESRI Virtual Earth System Research Institute – Schmidt Futures, funded by Eric and Wendy Schmidt.

Performing photosynthesis measurements in the climate-controlled growth chambers.

Characterisation of 'QTL-hotspot' introgression lines reveals physiological mechanisms and candidate genes associated with drought adaptation in chickpea



Phenotypic characterisation of 3D-leaf area in chickpea introgression lines (ILs) and their parental lines using the LeasyScan platform.

Project team: Dr Rutwik Barmukh[2,3], Dr Manish Roorkiwal[1,2,4] (project leader; mroorkiwal@uaeu.ac.ae), Dr Girish Dixit[5], Dr Prasad Bajaj[2], Dr Jana Kholova[2,6], Dr Millicent Smith[2,7], Dr Annapurna Chitikineni[2], Adjunct Associate Professor Chellapilla Bharadwaj[1,4,8], Professor Sheshshayee Sreeman[9], Dr Abhishek Rathore[2], Dr Shailesh Tripathi[8], Dr Mohammad Yasin[10], Dr Adiveppa Vijayakumar[11], Dr Someswar Rao Sagurthi[3], Hackett Professor Kadambot Siddique[1], Professor Rajeev Varshney[1,2,12]

Collaborating organisations: [1]UWA; [2]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); [3]Osmania University, India; [4]United Arab Emirates University, United Arab Emirates; [5]ICAR - Indian Institute of Pulses Research; [6]Czech University of Life Sciences Prague, Czech Republic; [7]The University of Queensland; [8]ICAR - Indian Agricultural Research Institute (IARI), India; [9]University of Agricultural Sciences, India; [10]Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, India; [11]UAS-Dharwad Regional Agricultural Research Station, India; [12]Murdoch University

'QTL-hotspot' is a genomic region on linkage group 04 (CaLG04) in chickpea (Cicer arietinum) that harbours major-effect quantitative trait loci (QTLs) for multiple drought-adaptive traits, and it therefore represents a promising target for improving drought adaptation.

To investigate the mechanisms underpinning the positive effects of 'QTL-hotspot' on seed yield under drought, we introgressed this region from the ICC 4958 genotype into five elite chickpea cultivars. The resulting introgression lines (ILs) and their parents were evaluated in multi-location field trials and semi-controlled conditions. The results showed that the 'QTL-hotspot' region improved seed yield under rainfed conditions by increasing seed weight, reducing the time to flowering, regulating traits related to canopy growth and early vigour, and enhancing transpiration efficiency.

Whole-genome sequencing data analysis of the ILs and parents revealed four genes underlying the 'QTL-hotspot' region associated with drought adaptation. We validated diagnostic KASP markers closely linked to these genes using the ILs and their parents for future deployment in chickpea breeding programs. The CaTIFY4b-H2 haplotype of a potential candidate gene CaTIFY4b was identified as the superior haplotype for 100-seed weight. The candidate genes and superior haplotypes identified in this study have the potential to serve as direct targets for genetic manipulation and selection for chickpea improvement.

This research is supported by the Bill & Melinda Gates Foundation, USA, and the Australia–India Strategic Research Fund from the Department of Biotechnology, Government of India.

Sneha Reddy examining chickpea plants at Nanaji Deshmukh Plant Phenomics Centre (NDPPC), New Delhi, India.

Physiology and proteomics profiling of chickpea genotypes in response to terminal drought

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[1,2], Professor Madan Pal Singh[1], Dr Sudhir Kumar[2], Dr Bhagya Dissanayake[1]

Collaborating organisations: [1]UWA; [2]Indian Council for Agricultural Research-Indian Agricultural Research Institute

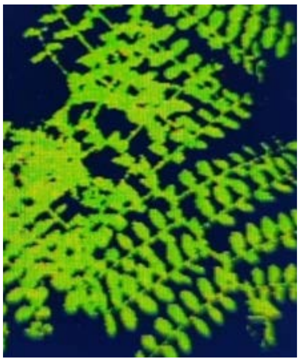
Chickpea is predominantly grown as a rainfed crop in arid and semi-arid regions that experience intermittent periods of drought stress. Terminal drought is a serious global concern, causing yield losses, predominantly in dry land areas of chickpea growing countries and is expected to increase due to global climate change. Comprehensive knowledge of physiological responses of plants under drought stress can aid in the development of drought-tolerant varieties. Under drought stress, proteins undergo several post-translational modifications (PTMs) and provide antioxidant defence, reducing the damage against photosynthesis, respiration, stomatal conductance and various cell signalling pathways.

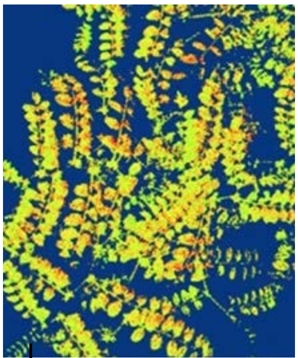
Although several stress-responsive proteins, biomarkers and signalling pathways associated with drought tolerance were identified in various crops, their practical application for the development of drought-tolerant varieties through genome editing and transgenic approaches is still in its infancy. Proteomics studies when analysed in conjunction with physiological mechanisms will help unravel potential proteins for drought tolerance. Moreover, the identification of differentially abundant proteins in the 'QTL-hotspot' region, using advanced proteomics tools will enable the screening and use of candidate proteins for crop improvement against drought stress.

The specific objectives of this study are:

1) To compare the genotypic differences in response to terminal drought for yield and yield components, amongst four different chickpea introgressed lines and their recurrent parents,
2) To understand the physiological processes associated with drought tolerance under terminal drought, particularly processes associated with photosynthesis and transpiration, and
3) To understand the proteomic processes associated with the drought 'QTL hotspot' region in roots under terminal drought conditions.

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





Hyperspectral images of a chickpea genotype under well-watered (top) and drought-stressed (bottom) treatment.

Processing of chickpea plants for imaging using the LemnaTec software on a high-throughput plant phenotyping platform.

Root diameter decreases and rhizosheath carboxylates and acid phosphatases increase in chickpea during plant development

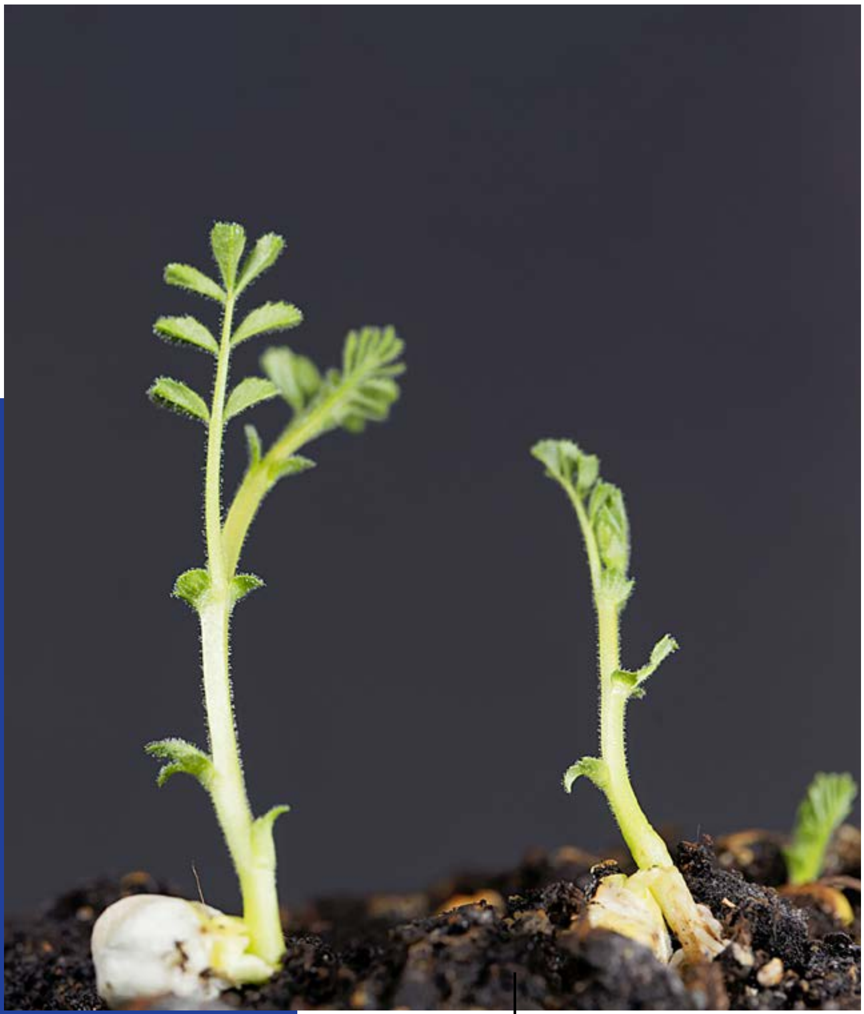
Project team: Dr Jiayin Pang[1] (project leader; jiayin.pang@uwa.edu.au), Hee Sun Kim[1], Dr Gustavo Boitt[1], Professor Megan Ryan[1], Zhihui Wen[1,2], Emeritus Professor Hans Lambers[1], Manish Sharma[1], Dr Bede Mickan[1], Gautier Gadot[1,3], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]China Agricultural University, China; [3]Institute Polytechnique UniLaSalle, France

This study investigated whether root traits at the seedling stage are maintained at the flowering stage in two chickpea (*Cicer arietinum*) genotypes with contrasting root morphology and physiology; and whether the genotype with greater rhizosheath carboxylates mobilises more poorly-available phosphorus (P) pools to increase shoot P at flowering/podding and seed yield at maturity.

Two chickpea genotypes were grown in a low P soil with or without P addition (0 and 40 µg P g^{-1} soil as KH_2PO_4) under controlled glasshouse conditions and harvested at seedling, flowering/podding, physiological maturity.

At the seedling and flowering/podding stages, ICC2884 had thinner roots and greater root mass ratio, specific root length and rhizosheath carboxylates per root dry weight (DW) than ICC456. Both genotypes had smaller root diameter, higher carboxylates and acid phosphatase activity in rhizosheath soil at flowering/podding than at seedling. In the rhizosheath soil of both genotypes, $NaHCO_3$-Pi concentration was depleted under P0 only; under both P0 and P40, $NaHCO_3$-Po concentration increased while NaOH-Pi and NaOH-Po concentrations decreased at the seedling stage but accumulated at the flowering/podding stage, relative to the bulk soil. ICC2884 did not mobilise more poorly available soil P or acquire more P at the seedling or flowering/podding stages or produce higher seed yields than ICC456.



First shoots of two young chickpea plants.

ICC2884 and ICC456 maintained the difference in root morphological and physiological characteristics from the seedling stage to the flowering/podding stage. The genotype with greater rhizosheath carboxylates (root DW basis) did not produce higher yield than genotype with less rhizosheath carboxylates.

This research is supported by UWA.

Securing a strong future for growing lentils in Ethiopia

Project team: Professor Martin Barbetti[1] (project leader; martin.barbetti@uwa.edu.au), Dr Ming Pei You[1], Adjunct Professor Roger Jones[1], Dr Asnake Fikre[2], Dr Seid Ahmed Kemal[3], Dr Joop van Leur[4]

Collaborating organisations: [1]UWA; [2]Ethiopian Institute of Agricultural Research; [3]ICARDA; [4]NSW Department of Primary Industries – Tamworth Agricultural Institute

This Australian Centre for International Agricultural Research (ACIAR) project, led by UWA, addresses the biotic challenges, particularly soilborne diseases, rust and viruses, that have devastated Ethiopian lentil crops in recent years.

In the mid-highlands of Ethiopia, lentils are one of the foundational legume rotation crops for more than 600,000 households in the mid-highlands of Ethiopia. They contribute 50 to 100 per cent of the cash earned by smallholder growers, enabling them to purchase necessary fungicides and fertilisers, pay children's school fees, and buy other less expensive food legumes. Additionally, lentil straw is a highly valued animal feed and can be sold for additional income. Traditionally, lentils were sown at the end of the rainy season to avoid severe epidemics of rust and root rot. However, changing seasonal conditions, such as more frequent drought periods that have fostered major virus disease outbreaks and untimely rainfall in November that favours major soilborne disease and rust epidemics, have had a disastrous effect on lentil productivity and local farmer incomes.

A team of Ethiopian, International Center for Agricultural Research in the Dry Areas (ICARDA) and Australian researchers will work with smallholders growing lentils in the cereal-based cropping systems of Ethiopia to maintain and improve their current lentil cropping practices, their cereal crops in rotation, and their livelihoods. ICARDA will provide lentil germplasm with high resistance to target diseases. Together, the research team will co-design with farmers new cropping management practices considering crop protection, genetics, agronomy, livestock nutrition and farming system analysis. Critical to this will be the adoption of the new practices for managing virus, soilborne and foliar diseases as a precursor to reducing the risk of lentil crop failure and increasing productivity and profitability of the farming system.

The collaboration between Australian and Ethiopian research institutes will involve germplasm exchange and the development of valuable yield and disease-resistance lentil variety traits, like root rot and virus resistances, and earliness that will also be important for the Australian lentil breeding program. Lentil is an important crop in Australia and the project will enhance the overall capacity of the Australian lentil industry to address current and future disease issues. UWA and NSW DPI researchers have already identified lentil genotypes with significantly improved resistance to soilborne, foliar and virus diseases that offer significant benefit to all countries involved.

This research is supported by ACIAR and UWA.

Photos clockwise from left:

Typical lentil root disease in a farmer's field in Ethiopia

Screening of Ethiopian lentil germplasm at UWA for resistance to soilborne diseases – note poor germination and growth of diseased plants on RHS compared with healthy controls on LHS

Lentil field screening against root rot in Ethiopia

Bean leafroll virus (BLRV) field screening by NSW DPI.

Faba bean gall pathogen *Physoderma viciae*: its phylogenetic variation and its enigmatic association with the field pea *Ascochyta* complex

Project team: Professor Martin Barbetti[1] (project leader; martin.barbetti@uwa.edu.au), Dr Ming Pei You[1], Beyene Bitew Eshete[2], Dr Seid Ahmed Kemal[3], Joop van Leur[4]

Collaborating organisations: [1]UWA; [2]Debre Birhan Agricultural Research Centre; [3]ICARDA; [4]NSW Department of Primary Industries – Tamworth Agricultural Institute

This project was the first to identify *Physoderma viciae* as the true cause of faba bean gall disease that devastates faba bean crops in Ethiopia and China with losses up to 100 per cent. The disease is especially devastating for the Ethiopian community as faba bean is of critical importance for food security. That it has now been shown to attack other crop (e.g., field pea) and forage (e.g., clover) legumes poses a serious international biosecurity risk for its potential to be accidentally introduced into other countries, including Australia.

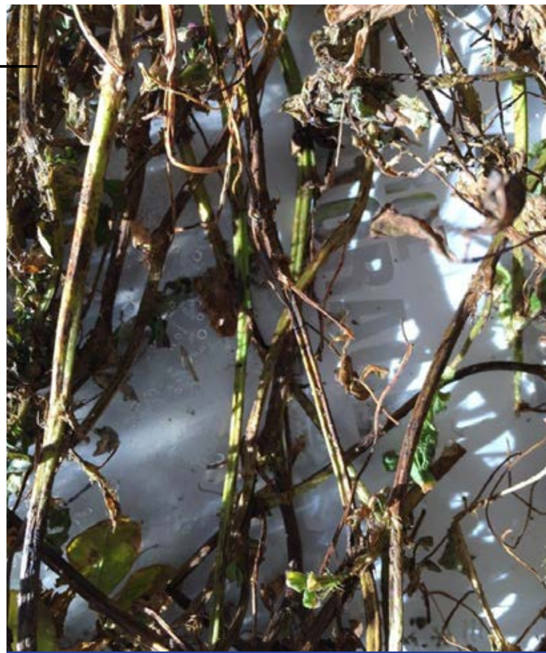
An extensive survey was carried out in October 2022 to further assess the ongoing severity of faba bean gall disease and the phylogenetic variation of the pathogen population. Current studies highlight that the phylogenetic diversity is dynamic and changing within *Physoderma* populations, a huge challenge to its future effective management. The same survey samples are also being utilised to try to explain the almost universal, but symptomless, presence of members of the field pea Ascochyta blight pathogen complex within faba bean infested by *P. viciae* in Ethiopia. There is a critical need for further evaluation and explanation of the occurrence and role of seemingly 'symptomless' legume pathogens in Ethiopia, Australia and worldwide. This is important both in relation to faba bean crops per se and, more widely, across the many situations where crop and/or forage legumes are grown in rotation, in proximity, and particularly where grown as mixed crop types such as faba bean/field pea mixtures as occurs in Ethiopia.

This research is supported by ACIAR and UWA.

Typical field symptom of Ascochyta blight on faba bean, a pathogen that (with or without showing symptoms) coexists with the faba bean gall pathogen.

Typical faba bean plant in the field severely affected by faba bean gall disease.

Typical Phoma Black Stem disease symptoms.



Phoma Black Stem severity and phytoestrogen production in annual *Medicago* spp.

Project team: Professor Martin Barbetti[1] (project leader; martin.barbetti@uwa.edu.au), Mahtab Omidvari[1], Dr Gavin Flematti[1], Dr Ming Pei You[1], Dr Payman Abbaszadeh-Dahaji[2]

Collaborating organisations: [1]UWA; [2]Vali-e-Asr University of Rafsanjan, Iran

Phoma black stem disease, caused by *Phoma medicaginis*, is particularly important and damaging to *Medicago* spp. in Australia. This disease not only greatly reduces herbage and seed yield but can stimulate production of phytoestrogens that negatively affect fertility and reproduction rates in grazing animals. Many different abiotic factors can also impact on production of phytoestrogen in forage legumes, yet surprisingly, the role of such factors is poorly understood, particularly in annual *Medicago* spp. While several biotic and abiotic stresses can stimulate phytoestrogen production in annual *Medicago* spp., it is the close relationship between the severity of Phoma black stem disease in annual *Medicago* spp. foliage with subsequent levels of phytoestrogen produced that is of most concern.

The aims of this project, as led by PhD candidate Mahtab Omidvari, were to:

1) Evaluate relationships between development and severity of the disease caused by *P. medicaginis* in different annual *Medicago* spp. and across different cultivars within individual species with consequent phytoestrogen production in the plant,
2) Define the relationship between plant maturity (plant growth stages) and phytoestrogen production in the presence of *P. medicaginis*, and
3) Define the relationship between concentration of *P. medicaginis* inoculum with phytoestrogen production; and fourth, the relationship between different abiotic stresses (e.g., temperature and moisture) with phytoestrogen production in the presence or absence of *P. medicaginis*.

Understanding the role of these 'factors' will not only enable choice of suitable annual *Medicago* spp. and cultivars that do not produce abundant phytoestrogen, but will provide a foundation for management options to reduce the current adverse influence of coumestan production stimulated by *P. medicaginis* on the reproduction of grazing animals.

These first and second studies were detailed in the IOA 2021 Annual Research Report. Subsequently, a third study was conducted to determine whether sequential infections by *P. medicaginis* increase production of phytoestrogens in annual medics, and whether genetic diversity of *P. medicaginis* isolates is correlated with the level of their pathogenicity and production of phytoestrogens. This study emphasised the importance of sequential inoculations when screening annual *Medicago* genotypes towards developing cultivars with superior disease resistance and enhanced animal reproductive outcomes.

The fourth study was undertaken to determine the impact of environmental variables temperature (12.5/9.5, 20/17, 27/24°C day/night) and soil moisture (100, 50 per cent WHC), and their interaction with *Phoma medicaginis* infection, on production of the phytoestrogen coumestrol in annual *Medicago rugosa* cv. Paraponto and *M. scutellata* cv. Sava. It was found that situations of higher temperatures in conjunction with lower soil moisture levels cause greatest elevation in coumestrol in the presence of *P. medicaginis*. For the fifth study, the effects of plant developmental stage (4, 6, and 10-week-old plants) of annual *Medicago rugosa* Paraponto and *M. scutellata* Sava and different inoculum concentrations of *P. medicaginis* (102, 103, 104, 106, 107 conidia/ml) in *M. littoralis* Harbinger and *M. polymorpha* Serena on disease development and coumestrol production were investigated.

These studies emphasised both the opportunity for farmers to better utilise annual *Medicago* spp. stands for grazing reproducing animals early in the growing season when both disease and coumestrol levels are lowest, and the need for heightened farmer vigilance at later growth stages with greater disease and consequent phytoestrogen risk for grazing animals.

This research is supported by UWA and the Australian Government Postgraduate Scholarship.

Phoma medicaginis visible in the leaves.

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

This project arises from the need to study the wheat streak mosaic virus (WSMV) complex in relation to:

a) Its seed-borne dispersion around the world,

b) The likely impact of global warming in accentuating the losses its epidemics cause globally, and

c) Its impact on global food security.

Wheat streak mosaic disease (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 has yet to be found in Australia but 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 very 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. WSMV was selected for the first phase of this project, and a research paper on its origins and dispersion around the world was published in 2022.

New complete open reading frame (CO) sequences from seven Australian WSMV isolates from WA or NSW were compared with 56 COs and 128 coat protein (CP) genes sequenced previously. Eleven CO and three CP sequences were recombinants, so were removed from the analyses. Patristic distances of maximum-likelihood phylogenies of non-recombinant (n-rec) CO sequences and their CP sequences were closely correlated ($R = 0.994$, $p \leq 0.00001$). The phylogeny of all 188 n-rec CP genes had four well-supported phylogroups (I–IV): phylogroup I (one Mexican sequence), phylogroup II (six Iranian sequences), phylogroup III (48 sequences) and phylogroup IV (133 sequences). Phylogroups III and IV basal (i.e., ancestral) Iranian sequences and either mostly European (phylogroup III) or mostly American (phylogroup IV) terminal sequences. Australian and South American sequences formed a phylogroup IV subcluster within a Pacific Northwest USA cluster. Unlike the Iranian, South American and European populations, the North American and Australian populations demonstrated recent population imbalance. Sample collection dates of 40 CO sequences were known, allowing WSMV phylogeny dating by RTDT methodology. The most recent WSMV ancestor was dated at 1456 CE, and the Australian cluster at 1998.7 CE, only two to three years before WSMV was first reported here. The virus genus WSMV belongs to (the Tritimoviruses) originated in central Eurasia.

This study concluded that; WSMV first entered wheat in its Middle East domestication centre, one basal lineage being taken to Mexico after the Spanish conquest, whereas the other most basal lineage spread throughout Iran, before spreading to other world regions. This dispersion occurred via dissemination of WSMV-contaminated wheat seed. Probable future spread to other world regions of additional WSMV phylogroups, and of inter-phylogroup recombinants, constitutes a biosecurity concern, including for Australia.

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

Severely stunted wheat plant with yellow streaky mosaic in upper leaves and killed lower leaves in NSW slopes region WSMV outbreak.

Foliage with WSMV yellow streaky mosaic in leaves of a wheat plant at Esperance.

Pasture virus disease research

Project team: Adjunct Professor Roger Jones[1] (project leader; roger.jones@uwa.edu.au)

Collaborating organisation: [1]UWA

What occurs when virus-infection is spreading within a mixed plant species population? This question is important not only for economically significant, mixed species managed systems but also for environmentally significant mixed wild species populations. It received attention in recently published ecological studies on wild plant species, but both these, and recent general pasture research publications, rarely mention earlier virus studies involving mixed species managed pasture. This project sought to rectify that situation by describing ten diverse examples of past research on mixed species managed pasture done over two decades on three continents that demonstrated plant species balance changes arising from virus-infection.

Three of the examples were from past Western Australian Research:

1) A long-term field experiment on species balance in sown annual pasture over a six-year period,
2) Alterations in species balance over a two-year period in sown perennial pasture, and
3) Pasture decline studies over 6-7 years in annual pasture. The other examples were from pasture field experiments in Victoria, Wales, Scotland and the USA states of Mississippi and North Carolina.

Taken together, all 10 of these examples showed that plants belonging to susceptible pasture cultivars sensitive to systemic virus infection are sufficiently weakened that their ability to withstand competition from non-host plants of other pasture species, or weed species, was diminished sufficiently to alter the plant species balance. Also, a similar alteration occurred when they were competing with virus-resistant or virus-tolerant host plants of the same or other pasture species, or a virus-resistant weed species. Such competition also diminished seed production which decreased their ability to regenerate. Notably, as reported subsequently with wild plant species populations, when two different pasture species infected by the same virus compete with each other, growth of the more sensitive species is suppressed. Since managed mixed species pastures constitute an important component of regenerative agriculture, retaining an optimal balance of pasture species and delaying pasture decline from weed invasion both require effective management of virus diseases.

To achieve its worthy global objectives of rehabilitating and improving farm ecosystems, benefitting farmers, and helping to address climate change – regenerative agriculture requires far greater future use of managed pastures. This not only necessitates optimising the balance of the pasture species for as long as possible within them but also significantly postponing their decline due to weed invasion. Since achievement of these two goals is threatened by pasture virus disease, virus control measures need to be included much more often in pasture management. Fortunately, for both annual and perennial pastures, integrated virus disease management strategies that were devised more than 20 years ago are already available to use for this purpose.

This research is supported by UWA.

Mini-sward originally sown with 26 per cent alfalfa mosaic virus (AlMV)-infected seed of cv. Circle Valley plant that became 100 per cent-AlMV infected, its infected plants developing symptoms of leaf mosaic and deformation, and premature plant senescence.

Mini-sward sown with healthy Medicago polymorpha (burr medic) cv. Circle Valley seed (control plot) consisting of vigorously growing healthy plants.

Sequencing historical crop virus isolates

Typical symptoms caused by carrot virus Y in carrot roots, with healthy carrot on left.

Project team: Adjunct Professor Roger Jones[1] (project leader; roger.jones@uwa.edu.au), Dr Ian Adams[2], Dr Adrian Fox[2], Dr Amie Fowkes[2], Samuel McGreig[2], Professor Neil Boonham[3], Dr Hollie Pufal[3], Emeritus Professor Adrian Gibbs[4], Dr Arnaud Blouin[5], Dr Mohammad Hajizadeh[6], Dr Segundo Fuentes[7], Dr Jan Kreuze[7], Professor Michael Jones[8], Dr John Fosu-Nyarko[8]

Collaborating organisations: [1]UWA; [2]FERA Science LTD, UK; [3]University of Newcastle, UK; [4]Australian National University; [5]University of Liège, Belgium; [6]University of Kurdistan, Iran; [7]International Potato Centre, Peru; [8]Murdoch University

This continuing project arises from the need to sequence genomes of historical isolates of agriculturally and environmentally damaging plant viruses studied during the era before nucleic acid (RNA and DNA) sequencing became widely used in the early 1990's. In 2022, four studies comparing historical and recent isolates of potato virus V (PVV), several Apiaceous viruses, tomato black ring virus, beet ringspot virus and subterranean clover mottle virus were completed and published. Examples of two of these and the citations to all five are given below.

Complete PVV genomes were obtained from 42 new isolates from Peru, which is within the potato crops main domestication centre, and eight from historical or recent PVV isolates from Europe (UK). These new genomes were compared with nine already published PVV genomic sequences. A phylogeny of the non-recombinant sequences found two major phylogroups, one of which formed three minor phylogroups (A1-A3) of isolates, all of which are only found in the Andean region of South America (Peru and Colombia), and the other formed two minor phylogroups, a basal one of Andean isolates (A4) that is paraphyletic to a crown cluster containing all the isolates found outside South America (World). This suggests that PVV originated in the Andean region with only one minor phylogroup spreading elsewhere in the world. 'Sub-tree dating' was done, which provided a 'Time to the Time to the Most recent Common Ancestor (TMRCA)' for PVV of 29 BCE. Thus, PVV arose at least 2000 years ago in the Andes, and was taken to Europe during the Columbian Exchange, where it diversified around 1853 CE soon after the European potato late blight pandemic.

A study of 10 preserved historical or recent virus samples of apiaceous plants included ones collected during surveys of Australian crops. Seven complete new genomic sequences and one partial sequence of the apiaceous potyviruses apium virus Y (ApVY), carrot thin leaf virus (CaTLV), carrot virus Y (CarVY) and celery mosaic virus (CeMV), were obtained. When these seven and 16 earlier complete non-recombinant apiaceous potyvirus sequences were subjected to phylogenetic analyses, they split into two separate lineages: 1 containing ApVY, CeMV, CarVY and panax virus Y and the other CaTLV, ashitabi mosaic virus and konjac virus Y. Preliminary dating analysis suggested the CarVY population first diverged from CeMV and ApVY in the 17th century, and CeMV from ApVY in the 18th century. They also showed the TMRCA of the sampled populations to be more recent: 1997 CE, 1983 CE and 1958 CE for CarVY, CeMV and ApVY, respectively.

This research is supported by UWA, the UK Department of Environment Food and Rural Affairs (DEFRA) Future Proofing Plant Health Project, EUPHRESCO VirusCurate project, CGIAR Research Program on Roots, Tubers and Bananas, CGIAR trust fund contributors, Peruvian Programa Nacional de Innovacion Agraria, The Bill and Melinda Gates Fund, University of Kurdistan, University of Liège, DPIRD, Murdoch University, and Belgian FPS Health Food Chain Safety and Environment.

Investigating herbicide tank mixes to control HPPD-resistant wild radish (*Raphanus raphanistrum*)

Project team: Dr Roberto Busi[1] (project leader; roberto.busi@uwa.edu.au), Dr Danica Goggin[1], Rex Cao[1], Mark Slatter[2]

Collaborating organisations: [1]UWA; [2]Nufarm Australia

Wild radish (*Raphanus raphanistrum*) is an economically damaging weed in Australia's farming system. Pyrasulfotole, a type of HPPD inhibitor, is a popular post-emergence broadleaf selective herbicide used in cereals in Australia. Repeated use of pyrasulfotole has led to resistance. More than one wild radish population has been found resistant to pyrasulfotole in Western Australia. Three field trials were conducted on two putative (42-2020 and 81-2021) and one previously reported (91-2020) hydroxyphenyl pyruvate dioxygenase (HPPD)-resistant wild radish populations in 2022 to determine the most-effective way to manage the resistance. The aims of this research project were to investigate alternate herbicide strategies to manage HPPD-resistant wild radish and understand the mechanisms of HPPD resistance in wild radish populations.

Field trials on three wild radish populations (42-2020, 81-2021, and 91-2020) revealed that the application of 50 g/ha pyrasulfotole (unregistered standalone use) resulted in 84, 35 and 58 per cent wild radish mortality, respectively, at 6 weeks after treatment. A mix of 50 g/ha pyrasulfotole + 250 g/ha bromoxynil resulted in 90, 81, and 84 per cent mortality, respectively. Population 42-2020 was confirmed to be moderately resistant to pyrasulfotole in pot screening, but the field application of pyrasulfotle treatments revealed lower resistance. We observed reduced efficacy on 81-2021 and 91-2020 populations which was consistent to previous pot-screening and field results. Additionally, though both populations 81-2021 and 91-2020 showed similar level of reduced efficacy on pyrasulfotole treatments, 81-2021 was more resistant (56 per cent mortality) to the post-emergence application of 96 g/ha mesotrione compared to 91-2020 (78 per cent mortality), suggesting there are different mechanisms contributing to HPPD resistance in the two populations. Cross-resistance to the PDS-inhibiting herbicide diflufenican was also observed in 81-2021, where the combination of 25 g/ha diflufenican + 50 g/ha pyrasulfotole resulted in only 48 per cent mortality. However, the picolinafen and pyrasulfotole tank mix improved the mortality to 94 per cent. Furthermore, adding 250 g/ha bromoxynil in diflufenican and pyrasulfotole mix resulted in respectively 94 and 100 per cent mortality to 81-2021 and 91-2020 populations. The four-way mix of diflufenican, bromoxynil, pyrasulfotole, and MCPA also resulted in equivalent control across both HPPD-resistant populations, with no significant crop damage observed in later assessments. Mesotrione, however, resulted in significant crop damage when applied at post-emergence as it is an off-label application.

The results of the field trials conducted in the WA wheatbelt have provided valuable insights of the increasing selection of HPPD resistant wild radish. Some populations clearly display resistance to multiple modes of action, now including group 27 herbicides. Conventionally, growers are educated to use different MOA herbicides in herbicide rotation to manage resistance. However, in this study, we found that two herbicides within the same herbicide group might elicit significantly different responses in a weed population. The HPPD resistant populations that displayed similar resistance to pyrasulfotole treatments exhibited different responses to another HPPD herbicide, mesotrione, suggesting the presence of multiple HPPD resistance mechanisms. The study in population 81-2021 indicated that cross-resistance to HPPD and PDS herbicides can lead to the failure of a diflufenican + pyrasulfotole tank mix treatment. Yet, resistance could be mitigated by replacing diflufenican with picolinafen, which could be a cost-effective option for managing HPPD and PDS cross resistance.

Additionally, the three-way and four-way mixtures (diflufenican bromoxynil + pyrasulfotole with or without MCPA) have been confirmed as effective in controlling HPPD- and PDS-multi-resistant wild radish. This study proposed some potential cost-effective herbicide tank mixes that can help growers and agronomists in managing HPPD and PDS resistant wild radish populations in the WA wheatbelt. The findings highlight the importance of developing integrated weed management strategies that incorporate different tank mix combinations with various molecules or three- and four-way MOA to effectively manage HPPD resistance and maintain the robustness of pyrasulfotole.

This research is supported by UWA and Nufarm Australia.

Resistant wild radish that survived from 50 g/ha pyrasulfotole + 250 g/ha bromoxynil application in WA wheatbelt.

Tank mix of three different herbicides (pyrasulfotole, bromoxynil and picolinafen) effectively controlled this type of resistant wild radish.

The intricate link between herbicide resistance, seed size, and seed dormancy: A threat to global crop production

Project team: Aniruddha Maity[2], Roberto Lujan Rocha[1] (project leader; roberto.lujanrocha@uwa.edu.au), Dr Yaseen Khalil[1], Dr Muthukumar Bagavathiannan[2], Dr Michael Ashworth[1], Professor Hugh Beckie[1]

Collaborating organisations: [1]UWA AHRI; [2]Department of Soil and Crop Sciences, Texas A&M University, USA

Herbicide resistance is a looming threat to crop production worldwide, as economically damaging weed species evolve to withstand these chemical onslaughts. The indiscriminate use of herbicides, without diverse weed control strategies, exerts immense selection pressure on weed communities, leading to the evolution of resistance and the development of adaptive traits like high seed dormancy.

To shed light on this issue, researchers conducted a comprehensive study in Western Australian grainbelt fields, comparing intensively managed (in-crop) populations with undisturbed ruderal areas. They focused on three weed species: rripgut brome (*Bromus diandrus* Roth), wild oat (*Avena fatua* L.), and hare barley (*Hordeum leporinum* Link; syn. *Hordeum murinum* L. *ssp. leporinum* (Link) Arcang.).

The study revealed intriguing findings regarding seed size variation. Species in intensively managed fields generally exhibited larger seeds than their ruderal counterparts, highlighting the influence of environmental and management factors on seed development.

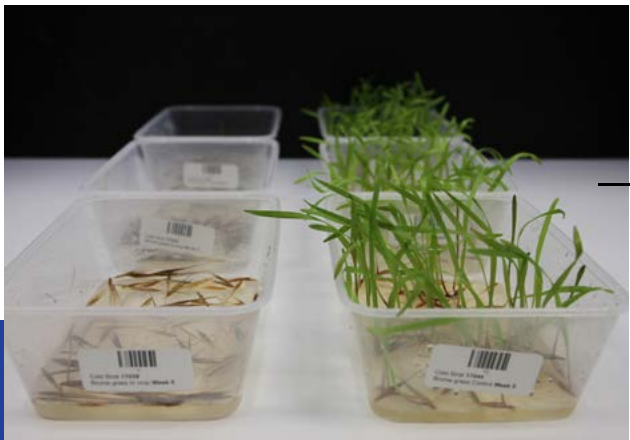
Notably, larger seeds displayed higher seed dormancy across all three species. Seed dormancy serves as a crucial survival mechanism, enabling seeds to delay germination until favourable conditions arise. Consequently, weed populations with increased seed dormancy become more resilient and challenging to manage.

The researchers also explored the connection between herbicide exposure and seed dormancy. Populations exposed to herbicides for extended periods showed significantly higher seed dormancy than those in ruderal areas. This link between herbicide resistance and seed dormancy poses a formidable challenge for weed management efforts.

The implications for weed management are clear: relying solely on herbicides is insufficient. Effective strategies require diverse and integrated approaches. Crop rotation, precision agriculture, and natural enemy introduction are among the potential tools to combat resistant weeds with dormant seeds.

This research is supported by UWA, AHRI and GRDC.

Shane Baxter (technician who helped during sample collection, experimentation and sample processing), and co-authors Roberto Lujan Rocha (Senior Research Officer at AHRI) and Aniruddha Maity (PhD candidate from Texas A&M University).



Highly dormant barley grass population on the left and a control population on the right. Most seeds of this population should have germinated about two months before this photo was taken for effective herbicide control.

Drone footage of sheep in the field at UWA Farm Ridgefield.
Photo: Jarryd Gardner

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.

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BeefLinks R&D Program

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Collaborating organisations: [1]UWA; [2]Ternes Agriculture; [3]MLA; West Midlands Group; Select Carbon; Rio Tinto

BeefLinks is a four-year collaborative research and development project between Meat & Livestock Australia (MLA) and UWA 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 explore and understand critical control points to produce evidence-based best practices and strategies for the management and movement of cattle. BeefLinks' goal is to develop a higher valued supply chain that is more productive and more sustainable for the WA beef industry. The program aims to deliver $72 million in net benefits to more than 750 producers through increased production of saleable and higher value beef, increased weaning rates, and cohesive landscape management for productivity and environmental outcomes.

The program will deliver information to support increased productivity including:

a) A better understanding of critical control points across the supply chain
b) Identification of best practice, practical strategies for the management and movement of cattle, and
c) Demonstrations, training opportunities and engagement with people and organisations across the WA supply chain.

In late 2022, project leader Professor Philip Vercoe presented on BeefLinks at the 11th annual Gascoyne Catchments Group Pastoral Forum in Coral Bay. More than 75 people attended the Forum to hear 15 expert presentations on a wide range of topics, including pastoral resilience, markets and profitability, research and technology and other relevant projects in the region. Professor Vercoe gave an update on the Australian-first virtual fencing trials, which stirred discussions on the different ways this technology could assist in the landscape. He also updated the audience on the CN30 project and what the proposed Zero Net Emissions Collaborative Research Centre (CRC) could mean for the beef industry.

This research is supported by UWA and MLA.

Professor Vercoe pictured with cattle wearing virtual fencing collars at Hamersley Station. Photo: James Liveris, ABC

Workshop underway at the 2022 Gascoyne Catchments Group Annual Pastoral Forum.

BeefLinks Backgrounding Project

Project team: Professor Philip Vercoe[1] (program leader; philip.vercoe@uwa.edu.au), Erin O'Brien[2] (project leader; beefofficer@wmgroup.org.au), Dr Nathan Craig[1,2]

Collaborating organisations: [1]UWA; MLA; [2]West Midlands Group

This project, led by West Midlands Group, aims to develop practical and robust management practices to improve the transition of animals from the pastoral zone into backgrounding systems, as well as between grazing rangelands and forage produced under pivots, to build more certainty in year-round supply of in-specification cattle.

The third year of the project (concluding in January 2023) focused on developing tools for decision-making. The team continued its station and farm visits, collecting data and analysing it to improve the dashboard tool. The project team also visited Coral Bay, which provided a unique opportunity to gather data and insights from a different location. The final dashboard tool was presented to the industry, showcasing the results and impact of the project. The team also participated in presentations and workshops, engaging with the industry and sharing its findings.

Overall, the BeefLinks Backgrounding Project has made significant progress in the last three years. It has established connections within the industry, gathered valuable data, and developed tools that will help farmers make informed decisions. The project has been a success, and I would like to extend my gratitude to all of the people involved who made it possible.

The project team worked to unite producers within the backgrounding sector, providing them with a deeper understanding of the supply chain and how to generate clear and concise data analysis. By building upon the knowledge of the northern beef cattle supply chain, the project facilitated more targeted and relevant information for producers in the region. Additionally, the project team established valuable connections between producers and research groups, encouraging ongoing collaboration and innovation in the industry.

Through the duration of the project, it was determined that providing data analysis for producers to give feedback on was a much more productive way to determine what information producers need to make management decisions. Each year, as we gained a better understanding of what information was required, we moved from graphs showing average daily gain against time, to a one-page dashboard report – ending with a two-page monthly report in the third year of the project. The data analysis in the project evolved over the three years and will continue to evolve to better suit producers in the northern beef cattle supply chain.

This research is supported by UWA and MLA.

West Midlands Group Beef Industry Development Officer Erin O'Brien.

Cattle as part of the BeefLinks Backgrounding Project. Photo: West Midlands Group

BeefLinks: Understanding supply chains, risks and mitigation strategies of northern beef producers in Western Australia

Project team: Dr Fiona Dempster[1] (project leader; fiona.dempster@uwa.edu.au), Associate Professor Maria Fay Rola-Rubzen[1], Asjad Tariq Sheikh[1], Tammie Harold[1], Dr Amin Mugera[1], Professor Philip Vercoe[1] (program leader; philip.vercoe@uwa.edu.au), Montana Walsh Baddeley[1]

Collaborating organisations: [1]UWA; MLA; DPIRD; Grazing Innovation; Rangelands NRM; Gascoyne Catchment Group; West Midlands Group; Kimberley Pilbara Cattlemen's Association

The WA northern beef industry comprises diverse enterprises interconnected in different ways. For the pastoralist, running a cow-calf enterprise is complex and challenging. The WA beef cattle supply chain pathways and decision points can be linear or looped, depending upon prevailing market and environmental conditions and individual producer motivations, risks, and constraints. A decision map, developed as part of this project, is available to view online. Productivity is measured via calving rates and mortality rates, however there are profound issues that limit the welfare, sustainability, and the industry's overall profitability. The study aims to identify perceived risk factors that are key to beef enterprises' performance and potential mitigation strategies currently in use to reduce risk.

Using a sample of beef producers in WA, data was collected through one-on-one interviews with the beef producers and station managers. The time frame for data collection was from December 2022 to February 2023. Producers were randomly selected from the database of beef producers. Of these, 43 were invited to participate in the study, and 14 agreed to the interview thus far. A seven-point Likert scale was used in this study, ranging from 1 (not at all risky/effective) to 7 (extremely risky/effective), to assess risk. In addition, the taxonomy of the questionnaire items was adapted from the literature and recommendations from experts to reduce the risk of misunderstanding the meaning of the statements.

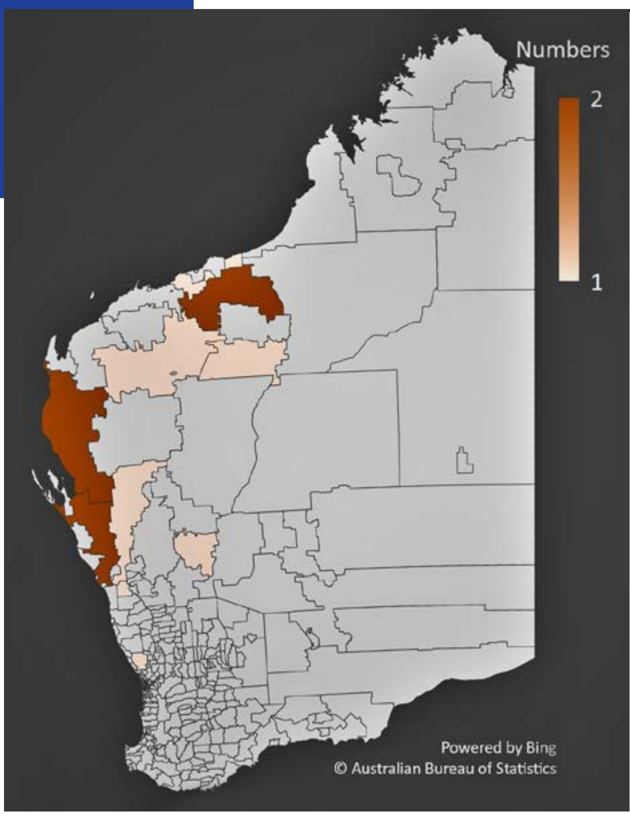
The preliminary analysis shows that the five main risks perceived by producers to beef enterprises' performance are:

1) Severe drought,
2) Erratic rainfall,
3) Lower domestic and global prices,
4) No social licence to farming, and
5) Mental health decline.

To mitigate the drought risk situation, the producers have been effectively adopting three main strategies: herd reduction (reduced carrying capacity), supplemented feed to address nutritional deficiency, and weaning calves earlier and providing them with essential vaccinations.

In addition, producers reported that adequate vaccination systems, low-stress stock handling, and inspecting herds at least twice a week, are the highest adopted practices to mitigate the impact of animal health risks. Other strategies for addressing drought and health risks include improving weight at joining through feed supplementation and managing young heifers separately from breeders.

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



A map showing the distribution of beef producers interviewed.

Cattle in the north of Western Australia. Photo: West Midlands Group

CRC for Net Zero Emissions from Agriculture

Project team: Professor Ben Hayes[2] (project leader; b.hayes@uq.edu.au), Lynne Turner[3], Professor Philip Vercoe[1], Professor Richard Eckard[4], Associate Professor Marit Kragt[1], Dr Matthew Morrall[2], Associate Professor Janelle Wilkes[5], Oliver Frith[2], Dr Ben Biddulph[6], Jackie Bucat[6], Professor Erik Veneklaas[1], Dr Caitlin Moore[1], Dr Heather Bray[1], Associate Professor James Fogarty[1], Wes Lawrence[7], Damon Buckley[8], Brad Wisewould[9], Dr Neil Canby[10]. Dr Deborah Cousins

Collaborating organisations: [1]UWA; [2]University of Queensland; [3]Queensland Department of Agriculture and Fisheries; [4]The University of Melbourne; [5]The University of New England; [6]DPIRD; [7]AxisTech; [8]SensorC; [9]CarbonAgSolutions; [10]Sunrise Energy Group

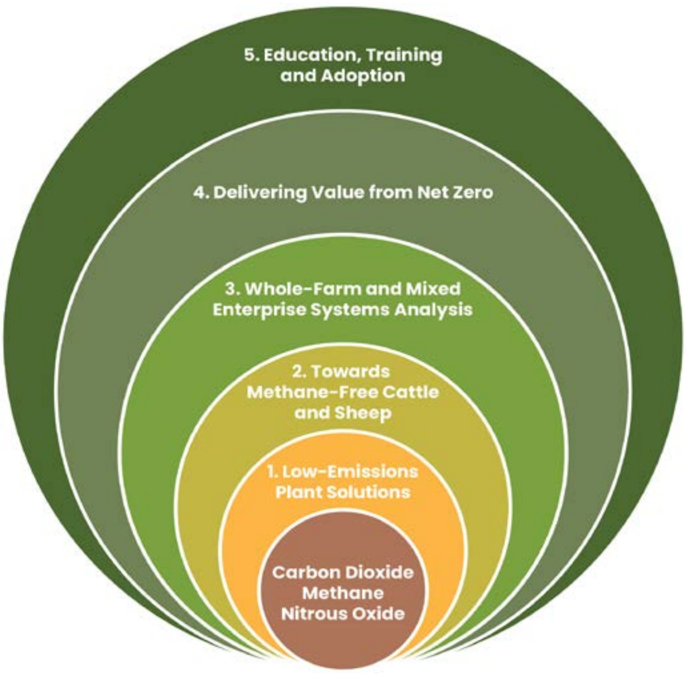
Members of The UWA Institute of Agriculture were heavily involved in the development of a CRC proposal on Net Zero Emissions from Agriculture in 2022.

The Zero Net Emissions from Agriculture Cooperative Research Centre (ZNE-Ag CRC) aims to catalyse 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. Our goal is to ensure Australia's agricultural industries keep growing, while they simultaneously achieve ZNE by 2040 and exceed international emissions reduction targets by 2050.

The CRC will harness and coordinate opportunities to create win-win through rapid research, development and adoption of science and technology-led solutions, driven by our industry and government partners. A Stage 1 proposal will be submitted in February 2023. At the time of writing, the CRC bid team is preparing their Stage 2 submission.

UWA Professor Philip Vercoe is nominated as research program lead for the Livestock program, and Associate Professor Marit Kragt is the nominated research lead for the Value from Net Zero program.

This proposal 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. The full list of project partners is available online.



A diagram outlining the approaches for CRC for Net Zero Emissions from Agriculture.

Dr Zoey Durmic and Peter Hutton at Rio Tinto Hamersley Station.

BeefLinks: Carbon Neutral 2030

Project team: Professor Philip Vercoe[1] (project leader; philip.vercoe@uwa.edu.au), Dr Zoey Durmic[1], Dr Peter Hutton[1], Dr Lindsey Perry[2]

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

The Australian red meat industry has set a target to be carbon neutral by 2030. This BeefLinks project aims to assist producers in the northern rangelands of Western Australia to achieve reduced livestock emissions through optimising a low methane, nutritive feedbase.

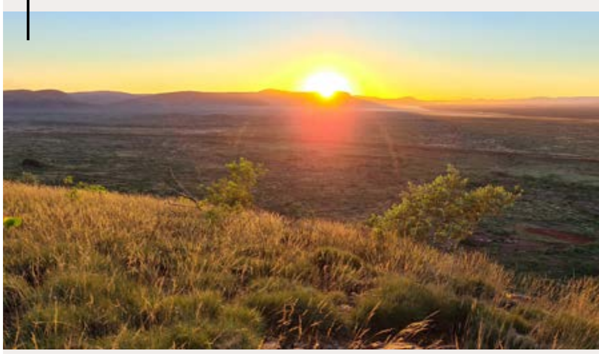
This discovery project seeks to determine the methane-mitigating potential of over 100 native rangeland forages that may support a low carbon feedbase and value chain for the northern beef industry. Researchers work with stations/backgrounders and stakeholders to develop a broader understanding of the northern feedbase. They collect samples, test and build a database of native forages in the northern feedbase, characterised by nutritional and methane-reducing properties, and develop tools for northern producers to make informed decisions about feedbase mix for optimal nutrition and methane mitigation.

Learnings up to the end of 2022 include:

a) There are potent anti-methanogenic species in the WA rangelands,
b) There is great diversity in nutritional and fermentation characteristics,
c) Continuing to characterise the rangeland species will inform grazing management strategies, and
d) There is potential for rangeland plants to reduce methane emissions from cattle.

This research is supported by UWA and MLA.

Sunset over ranges near Hamersley Station in the Pilbara.



UWA Master's student Georgia Welsh.

Predicting water intake and drinking behaviour in sheep

Project team: Georgia Welsh[1], Associate Professor Dominique Blache[1] (project leader; dominique.blache@uwa.edu.au), Dr Shane Maloney[1], Dr Serina Hancock[2]

Collaborating organisations: [1]UWA; [2]Murdoch University

This project investigated an algorithm to predict water intake and drinking behaviour in sheep, using a measured drop in rumen temperature from a rumen temperature logger. The formula was developed using water temperature and body mass to calculate an effective rumen volume, which could be applied to a thermodynamics equation to predict water intake volume and frequency.

This Master of Agricultural Science (Crop and Livestock Farming Systems) was completed in December 2022 by UWA student Georgia Welsh. It was part of a larger program named 'The impact of shade and shelter on sheep reproduction and welfare' funded by MLA under the Sheep Reproduction Strategic Partnership. The data collected in this project will be used to establish the optimum quantity and quality of water to provide merino ewes during joining, to mitigate the effects of heat stress on reproductive performance.

In 2023, UWA researchers will continue investigations into predicting volume of water consumed in a paddock scenario at UWA Farm Ridgefield in Pingelly. Their work will provide information about the intricate relationship between shade availability, climatic condition, and water intake behaviour.

This research is supported by UWA, MLA, and the WA Livestock Research Council.

Annual Legume Breeding Australia

Project team: Associate Professor Phillip Nichols[1] (project leader; phillip.nichols@uwa.edu.au), Bradley Wintle[1], Professor Megan Ryan[1], Professor William Erskine[1], Gereltsetseg Enkhbat[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*), arrowleaf clover (T. *vesiculosum*) and other legumes.

Breeding highlights include seed increase by DLF Seeds of two new sub clovers developed by ALBA, while a third sub clover was multiplied up at UWA Shenton Park Field Station, following completion of Stage 2 field trials in WA, Victoria, New South Wales and New Zealand. New Stage 2 trials of 29 early flowering sub clover breeding lines were sown at UWA Farm Ridgefield and other low rainfall sites across southern Australia, while an elite midseason sub clover cohort was selected from 82 lines for Stage 2 field trials in 2023.

Selection continued on breeding populations of balansa clover, arrowleaf clover and Persian clover at Shenton Park and Manjimup. In 2022, ALBA PhD candidate Gereltsetseg Enkhbat completed studies on waterlogging tolerance of ssp. *yanninicum* sub clover.

This research is supported by UWA and DLF Seeds.

Breeders seed increase of a new subterranean clover cultivar.

ALBA subterranean clover breeding rows at UWA Shenton Park Field Station.

Pingelly Merino Lifetime Productivity Project at UWA Farm Ridgefield

Project team: Dr Bronwyn Clarke[2] (project leader; bronwyn.clarke@murdoch.edu.au), Emeritus Professor Graeme Martin[1], Professor Andrew Thompson[2], Professor Daniel Brown[3], Dr Peter Wahinya[3], Dr Sam Walkom[3], Geoff Lindon[4], Anne Ramsay, Brett Jones

Collaborating organisations: [1]UWA; [2]Murdoch University; [3]University of New England; [4]Australian Wool Innovation

Seven years of dedication research as part of the Pingelly Merino Lifetime Productivity Project culminated in a final field day at UWA Farm Ridgefield in late October 2022. The event attracted a crowd of about 80 researchers and farmers to hear preliminary results from the project and get one last look at the sheep involved in the trial. Following the event, the ewes underwent one last classing and shearing before the Ridgefield-based trial was officially concluded.

The Australian Wool Innovation (AWI)-funded and Australian Merino Sire Evaluation Association-facilitated MLP project, supported by Murdoch University, UWA, and the Federation of Performance Sheep Breeders along with the Site Committee, has run at Ridgefield since 2015. Murdoch University Senior Research Fellow and MLP Pingelly Site Manager Dr Bronwyn Clarke led the project. The ewe progeny born in 2016 and 2017 from 29 diverse Merino sires have now been evaluated for their lifetime productivity.

The ewes were visually classed each year and had measurements taken for weight, condition score, wool quality, fleece weight, fat and eye muscle depth. Additionally, the ewes have been naturally mated each year and had their reproductive performance evaluated in terms of conception rate, number of lambs weaned and the weaning weight of their lambs.

The field day was chaired by Site Committee Chair Brett Jones, who introduced a line-up of speakers including Dr Clarke, the University of New England's Animal Genetics and Breeding Unit scientists Professor Daniel Brown, Dr Peter Wahinya and Dr Sam Walkom, as well as AWI's Genetics Program Manager Geoff Lindon and MLP Project Manager Anne Ramsay. In her presentation, Dr Clarke explained how early flock breeding values were a good predictor of lifetime performance for wool and growth traits, but reproduction traits weren't as well predicted by just one or two measurements. Even though the project has now come to an end, the wool industry can look forward to the analysis and presentation of the results of such an important project continuing over the next four years.

This research is supported by UWA, the Australian Wool Innovation, Australian Merino Sire Evaluation Association, Murdoch University, and Federation of Performance Sheep Breeders.

Sheep involved in the trial at UWA Farm Ridgefield.

Presenters and stakeholders at the final Pingelly MLP Project field day.

Rams in Ridgefield farmyards, returning to the yards at the end of another study day.

Oestrogenic clover transiently disrupts ram reproduction

Project team: Dr Kelsey Pool[1] (project leader; kelsey.pool@uwa.edu.au), Associate Professor Dominique Blache[1], Professor Megan Ryan[1], Dr Kevin Foster[1], Dr Tim Watts[1], Luoyang Ding[1], Gerelee Ehkbhat[1], Tayler Kent[2]

Collaborating organisations:
[1]UWA; [2]Murdoch University

In sheep, intake of oestrogenic pastures is shown to severely compromise reproductive function in the ewe and represents an ongoing hinderance to sheep production systems. Despite a lack of research into whether phytoestrogens compromise male fertility, it is currently considered safe for breeding rams to graze oestrogenic pastures.

Our research finds that dietary phytoestrogens disrupt a specific stage of ram spermatogenesis, causing subtle decreases in sperm quality by affecting the expression of pathways involved in the structural integrity of the spermatozoa.

This study demonstrates for the first time that ram reproduction is compromised by oestrogenic pasture, whilst also providing a longitudinal model for the impact of phytoestrogens on male fertility. Our research shows that the phyto-oestrogens associated with clover disease detrimentally impact sperm function in vitro, reducing fertilising potential. In rams grazing oestrogenic pasture, reproduction is also reduced, however this effect is transient and does not persist to the following breeding season.

We have had the opportunity to convey some of this information to producers and industry partners in WA during conferences in Southern WA and NSW. This project has so far produced three publications. The information from these studies is likely to inform upon policies and recommendations concerning the grazing of livestock on oestrogenic pastures.

This research is supported by UWA, the E.H.B Lefroy Bequest and MLA.

Dr Kelsey Pool, Research Assistant Rebecca Taylor and Yangzhou University Exchange student Feifan Wu assess ram sperm quality in a transient lab at UWA Ridgefield farm old shearing shed.

PhD candidate Doraid Alkhishshaybi and Dr Kelsey Pool collecting blood samples from the rams at UWA Farm Ridgefield.

Professor Simon de Graaf, Dr Jessica Rickard, Dr Kelsey Pool and Dr Taylor Pini.

Climate-ready rams: How does heat stress impact ram reproduction?

Project team: Dr Kelsey Pool[1] (project leader; kelsey.pool@uwa.edu.au), Doraid Alkhishhaybi[1], Associate Professor Dominique Blache[1], Professor Shane Maloney[1], Dr Luoyang Ding[1], Dr Hayley Norman[2], Dr Serina Hancock[3], Callum Connolly[1]

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

With climatic extremes and heatwave events becoming more frequent, the interplay between temperature and reproduction is increasingly critical for livestock production. Sheep joining occurs during summer and though heat stress is known to compromise male fertility, the exact timing and impact on spermatogenesis, and how this translates into production outcomes, has not been clearly evaluated.

A transient lab to measure sperm quality was set up and packed down every week for 3 months in the old shearing shed. This allowed researchers to look at sperm production and quality in real time on-farm.

This project aimed to quantify the impacts of extreme temperature events and paddock microclimate on ram reproductive capacity. Using on-animal biosensors and intensive on-farm analysis of semen quality, the reproductive function and behaviour of rams was evaluated in the weeks prior to, during and after joining. A potential intervention to improve ram reproductive function, melatonin, was also implemented.

Though still undertaking data analysis, we have so far observed evidence of the specific pathways via which heat stress contributes to the decline of ram reproductive function and have identified key periods during which rams are at risk of reduced fertility.

Increasing knowledge around factors that can decrease ram reproductive function is critical for production outcomes. As rams are typically joined at a ratio of 1-2 rams to every 100 ewes, a reduction in male fertility can significantly reduce annual production. A better understanding of the relationship between temperature and male fertility will inform upon ram management strategies in preparation for joining.

This research is supported by UWA, MLA and Ceva Animal Health Australia.

Establishment of WA Semen Standards Reference Laboratory at UWA

Project team: Dr Kelsey Pool[1] (lab leader; kelsey.pool@uwa.edu.au), Professor Simon de Graaf[2] (project leader; simon.degraaf@sydney.edu.au), Dr Taylor Pini[3], Dr Jessica Rickard[2]

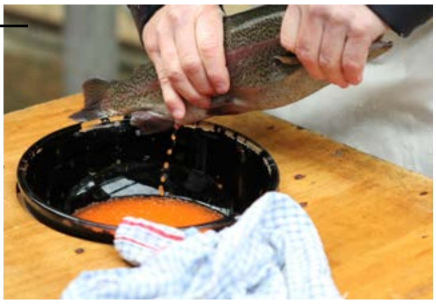
Collaborating organisations: [1]UWA; [2]The University of Sydney; [3]The University of Queensland

The first collaborative university and internally standardised livestock semen testing business in Australia launched in 2022, with one of three founding commercial andrology labs based at UWA. UWA School of Agriculture and Environment and The UWA Institute of Agriculture research associate Dr Kelsey Pool runs the WA Semen Standards Reference Laboratory at UWA's Crawley campus as well as travelling across WA to deliver on-site consultancy.

Lefroy Fellow Dr Pool's expertise in semen assessment and sperm biology research contributes to a better mechanistic understanding of reproductive biology and provides tangible outcomes to animal production industries. The Reproduction Company services clients across Australia, representing more than 20 businesses, over 1000 sires and several thousand successful inseminations – with about 40 per cent of those currently in WA.

This research is supported by UWA, The University of Sydney, and The University of Queensland.

Stripping trout eggs during breeding season.



Global warming-resilient trout offer hope in the face of climate change

Project team: Adjunct Associate Professor Craig Lawrence[1] (project leader; craig.lawrence@uwa.edu.au), Olivia Adams[2], Dr Yangfan Zhang[3], Dr Mathew Gilbert[2], Dr Michael Snow[4], Professor Anthony Farrell[2]

Collaborating organisations: [1]UWA; [2]University of British Columbia; [3]Harvard University; [4]Aquatic Life Industries; DPIRD Pemberton Hatchery

An international team of researchers from UWA, University of British Columbia, Canada and Harvard University, USA have shown that an isolated trout population from Western Australia may offer aquaculture and recreational anglers an answer to global warming.

Aquaculture and wild fish stocks have experienced losses due to global warming. This is particularly important for Rainbow trout, that are farmed worldwide, but are considered a cold-water species only suitable for water temperatures between 5°C-20°C. For more than 10 years there has been a global search for a trout strain that will enable aquaculture to continue as water temperatures increase.

Unlike elsewhere in the world an unusual trout population from Pemberton in WA has thrived despite increasing water temperatures. Their ancestors were introduced to WA for aquaculture and recreational stocking where they have been isolated for over 25 generations. At the Pemberton hatchery, summer heat waves over the past 50 years have unintentionally selected for fish with impressive upper temperature limits.

In this study we raised groups of trout at six different temperatures ranging from 15 to 25°C, then exposed them to increased temperatures. Typically, to understand how fish cope with increased temperature, scientists focus on one or a few measures, such as growth or upper temperature limit, in a single study. But in the most comprehensive study to date, we looked at how temperature affected the growth, energy it takes to digest a meal, physical fitness, upper temperature limit, ability to withstand low oxygen, and heart rate of these fish.

Just about every aspect of the performance of these rainbow trout peaked in the groups of fish raised at 17–23°C. At these temperatures, fish had the best growth, used the least energy to digest food and were the most physically fit. These fish could even endure temperatures up to 31°C before losing balance (which is how scientists typically measure a fish's upper thermal limits), which is an incredible feat when rainbow trout from elsewhere in the world do best below 20°C.

Due to a combination of artificial and natural selection, the increased temperature tolerance of the Pemberton rainbow trout line compared to stocks elsewhere in the world, means that this unique strain will be important for the future of aquaculture in a warming climate.

This research is supported by UWA, the Natural Sciences and Engineering Research Council of Canada, Elizabeth R Howland Fellowship, and Pei-Huang Tung and Tan-Wen Tung Graduate Fellowship. Mitacs Globalink Research funded travelling fellowships from the Company of Biologists.

Trout pictured swimming in an aquaculture system.

Aquatic AI co-founders Michael Storey and Andrew Walker, with lab Technician Richard Linney holding a marron. Pictures Jarryd Gardner

Marron is a premium freshwater crayfish that grows in value as the world moves towards sustainable seafood.

Scaling a technology-enabled intensive marron farm

Project team: Michael Storey[2] (project leader; michael@aquaticai.com), Andrew Walker[2], Richard Linney[2], Adjunct Associate Professor Craig Lawrence[1], Dr Belinda Martin[1], Dr Leah Beesley[1], Dr Jen Middleton[1]

Collaborating organisations: [1]UWA; [2]Aquatic AI

Endemic to the south-west of WA, marron is Australia's largest commercially available freshwater crayfish and the third largest in the world. With market demand for marron outstripping supply, agri-tech start-up Aquatic AI are working with UWA scientists on a modern and more sustainable way of farming marron. They are developing an innovative vertical farming system at UWA Shenton Park Field Station.

The vertical farming system may resolve issues of labour and land requirements that have historically stunted the marron industry's expansion. Aquatic AI have funding and support from AgriFutures Australia, industry partners across the supply chain, and financial and scientific backing from UWA.

Traditional marron farming in outdoor ponds yields about three or four marron per square metre. In their trial laboratory, which uses a tank stacking system to optimise its physical footprint, Aquatic AI has achieved yields of more than 100 marron per square metre. By using robotics and data analysis, they expect to increase that number to around 1000 marron per square metre. The UWA research team are also optimising the nutrition and sale size of the marron to balance flavour, market demands and cost.

In 2023, Aquatic AI will be looking for investment to continue the project and fit out the robotics in the lab, with the aim to move forwards to commercial scale production.

This research is supported by UWA, Aquatic AI, AgriFutures Australia, and industry partners.

Utilising insect meal in freshwater aquaculture

Project team: Isobel Sewell[1], Dr Craig Lawrence[1], Associate Professor Jan Hemmi[1] (project leader; jan.hemmi@uwa.edu.au), Associate Professor Julian Partridge[1], Dr Gavin Partridge[2]

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

Capture fisheries and fish aquaculture sectors play a crucial role in providing food, income, employment and an array of social and cultural values to many populations. The management of fishery resources and the progression towards a sustainable industry in terms of conserving these resources is, therefore, important from a food security perspective. The current rate of production for marine derived fish meal is insufficient to cover growing demand, especially considering carnivorous aquaculture finfish and crustaceans have large protein requirements, commonly in the form of fish meal. Insects are a natural part of many freshwater and marine carnivorous finfish and crustacean diets. Black soldier fly larvae (BSFL) are of particular interest as a substitute to fish protein in aquaculture diets as they very efficiently convert organic matter into their own biomass, resulting in high protein and lipid concentrations. Isobel Sewell's thesis has been investigating the use of BSFL as an alternative to fish protein in barramundi and marron aquaculture diets. Based at the UWA Shenton Park Research Station Aquaculture Facility, the aim of this research is to reduce the aquaculture industry's reliance on diminishing wild fish stocks and, in the process, recycle the by-products of other industries by utilising their organic waste (e.g., unmarketable vegetables).

In 2022, PhD candidate Isobel Sewell quantified the potential of a BSF larvae diet by measuring the barramundi and marron's growth and wellbeing. The results have shown that BSF larvae is viable in freshwater aquaculture diets. The barramundi had comparable growth rates to those on a commercial (BSF larvae-free) diet. In addition, the marron trial has produced some interesting results, suggesting the inclusion of BSF larvae promotes higher growth. In June, Ms Sewell presented her postgraduate research achievements at The UWA Institute of Agriculture's 16th annual Postgraduate Showcase.

PhD candidate Isobel Sewell at the UWA Shenton Park Research Station Aquaculture Facility. Photo: Corrina Ridgway

This research is supported by the Robson & Robertson Award and Fisheries Research and Development Corporation with contributions from UWA, DPIRD, ChemCentre, Future Green Solutions, GEA and Ridley AgriProducts.

Isobel holds up a marron during sampling at Shenton Park.

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], Domenico Volpicella[1]

Collaborating organisation: [1]UWA

Agrobiodiversity is critical to food security, yet for the past half century, livestock breed and bloodline extinctions have increased 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 2022, a strong focus was industry and community engagement, with the project leader Dr Catie Gressier presenting the after-dinner talk at the Australian Highland Cattle Society annual show. Dr Gressier penned several articles for breed association newsletters and blogs, as well as rural newspapers. She has also aimed to raise public awareness of these issues through radio interviews, presenting numerous public lectures and conference presentations across Australia and in Europe, and through her role as Director of the Rare Breeds Trust of Australia.

Tammi Jonas, a PhD candidate within the project and a farmer and activist, in 2022 had her farm featured on Zac Efron's *Down to Earth* Netflix program, while being interviewed in the ABC 4 Corners' investigation The Butchers from Brazil. She was featured in *Heartland Stories Radio* podcast, in the episode 'Tammi Jonas: the Story of a Farmer, Agroecologist, and Mindful Meatsmith', in addition to travelling to Wakelyns Farm in the UK to participate in an Agroecology Dialogue, in addition to presenting at the Oxford Real Farming Conference.

PhD candidate Domenico Volpicella has conducted extensive fieldwork with native, rare and heritage breed poultry producers in Italy and Australia and is busy exploring their work through a degrowth lens.

This research is supported by UWA, and the Australian Government through the ARC Discovery Project scheme (project number DE200100595).

Moving endangered large black pigs on Tammi Jonas's farm.

Project leader Dr Catie Gressier with a Lincoln lamb at the Perth Royal Show. Lincoln sheep are listed as 'critical' by the Rare Breeds Trust of Australia, with less than 75 annual registrations.

Dawn reflections over Bindoola Gorge, Hone Valley Station in the Kimberley WA.
Photo: Janelle Lugge

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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.

Theme Leaders

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Associate Professor Sally Thompson and Sensoil Director Professor Ofer Dahan following his UWA lecture.

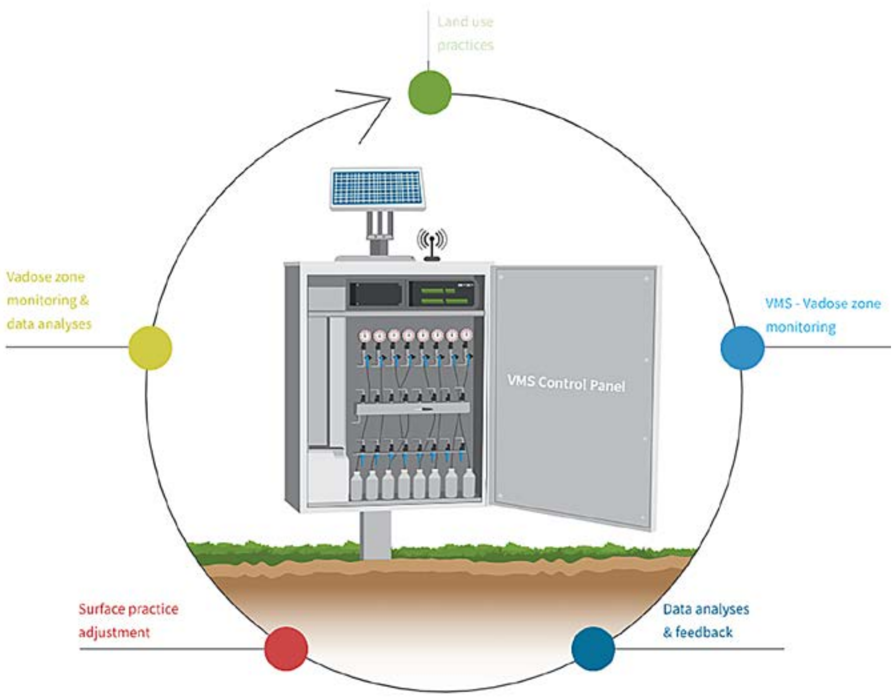
VMS system for the OzCZOs ready to be shipped from Israel.

Preparation for the Sensoil VMS installation at UWA Farm Ridgefield

Project team: Associate Professor Sally Thompson[1] (project leader; sally.thompson@uwa.edu.au), Professor Matthias Leopold[1], Professor Ofer Dahan[2]

Collaborating organisations: [1]UWA; [2]Ben-Gurion University of the Negev, Israel; TERN; AuScope

The technology and equipment to install a Sensoil real-time soil sensing technology Vadose-zone Monitoring System (VMS) at UWA Farm Ridgefield was shipped from Israel to UWA in October 2022. The partnership between UWA and Sensoil, with support from TERN and AuScope, is an essential component of the Australian Research Council-funded Critical Zone Observation (OZCZO) network. UWA Farm Ridgefield is among five sites in the national OZCZO network, which includes the University of Adelaide, University of the Sunshine Coast, James Cook University, and the University of New South Wales.



An illustration of the VMS control panel.

Once installed, researchers will use state-of-the-art, automated monitoring infrastructure to observe stocks and flows of carbon, water, energy, and mass across the Critical Zone (the vertical span from plant canopies to bedrock) in the WA wheatbelt. VMS monitors the unsaturated zone from land surface to groundwater. The VMS provides real time information, on pollution processes taking place in the unsaturated zone, long before they accumulate in the aquifer. Equipped with advanced sensors and pore-water sampling units, VMS enables the retrieval of accurate, relevant information on water percolation and contaminate transport. Monitoring real-time migration of contaminants provides critical, accessible information on the hydrological and chemical conditions in the vadose zone. Data obtained via the VMS, enables direct assessment of water percolation velocities and contamination migration fluxes in the subsurface.

The VMS is based on more than 15 years of research led by Sensoil co-founder Professor Ofer Dahan. Professor Dahan delivered a special lecture for IOA at the UWA Agriculture Lecture Theatre in November 2022. Installation of the VMS system at Ridgefield is planned for early 2023.

This research is supported by UWA.

Prioritising engagement of a diverse student cohort in online hydrology learning at The University of Western Australia

Project team: Associate Professor Sally Thompson[1] (project leader; sally.thompson@uwa.edu.au), Dr Sarah Bourke[1], Professor Nik Callow[1], Associate Professor Matthew Hipsey[1]

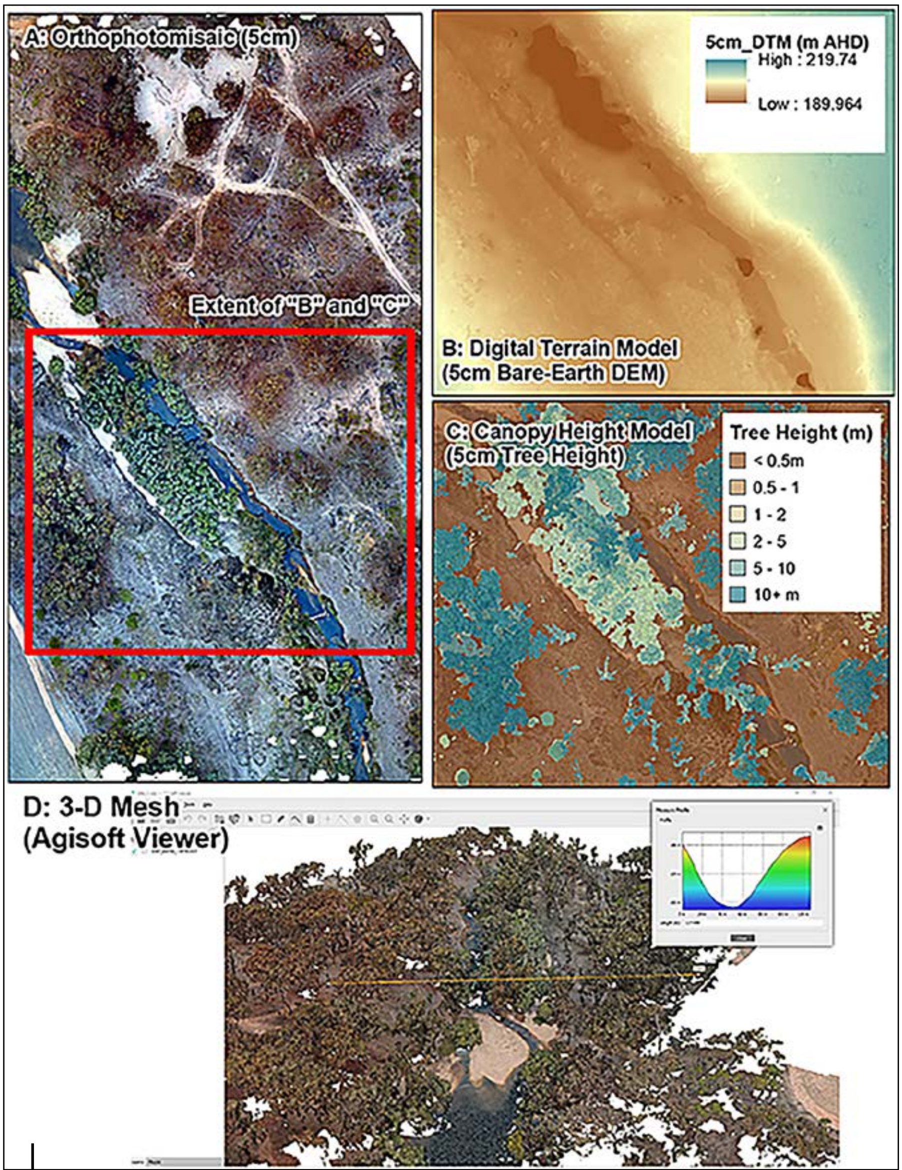
Collaborating organisation: [1]UWA

Like most water education institutions worldwide, hydrology instructors at UWA had to rapidly adapt traditional teaching strategies to manage the COVID-19 pandemic. With diverse student cohorts, including a large fraction of international students prevented from reaching Australia by travel restrictions, key requirements from this transition were to create supportive, inclusive online educational settings, and to maximise student engagement in their courses.

Here, we draw on experiences in four hydrology courses to illustrate how we used a holistic approach spanning course structure, content delivery, active learning experiences and authentic assessment to protect these key pedagogical requirements during the transition to online learning. Some aspects of this approach for example, creating an online 'virtual watershed' in lieu of field trips required sophisticated technology to support online innovation. Other aspects, however, relied primarily on existing features in learning management systems such as Blackboard and on re-organisation of course structure and communication approaches to support online learning, with minimal need for new technology or software.

The outcomes in these courses as measured by student engagement, enrolment and self-reported satisfaction were positive, with student evaluations remaining similar to those of pre-pandemic levels. Previous interest in running flipped classrooms and familiarity with technology among instructors and students were helpful in enabling the transition. While content-delivery may remain in an online mode for hydrology classes at UWA long term, opportunities to re-introduce field work, laboratories and other face-to-face active learning activities are eagerly awaited by instructors and students alike.

This research is supported by UWA.



Example of digital field sites constructed from drone photogrammetry to create various types of digital field data in-lieu of field data collection.

Organisation of the soil profile controls the risks of runoff in the humid Ethiopian Highlands

Project team: Dr Liya Weldegebriel[2] (project leader; liyanet@stanford.edu), Associate Professor Sally Thompson[1], Professor Seifu Tilahun[3,4], Professor William Dietrich[5], Dr Shmuel Assouline[6], Professor Jan Nyssen[7]

Collaborating organisations: [1]UWA; [2]Stanford University, USA; [3]Bahir Dar Institute of Technology, Ethiopia; [4]Texas A & M University, USA; [5]University of California, USA; [6]Volcani Institute, Israel; [7]Ghent University, Belgium

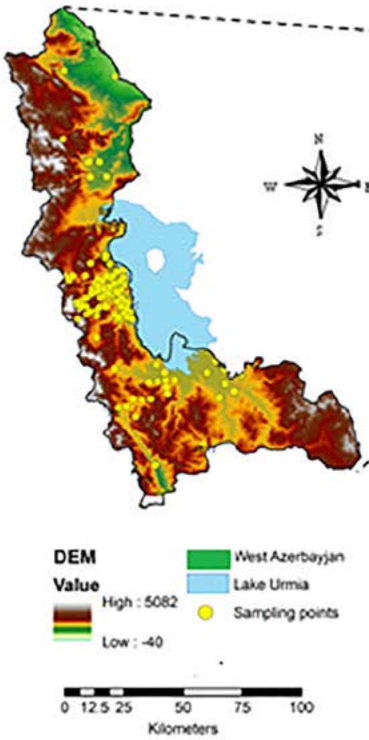
Erosion of agricultural land endangers the livelihood of millions of people who depend on natural resources. Soil and water conservation practices (SWCP) are intended to reduce runoff production and erosion. Understanding surface runoff drivers are crucial for the effective design and implementation of SWCPs.

We present field observations of complex vertical soil profiles and variations in lithology along hillslopes ridge-channel transects from the Debre Mawi watershed in the upper Abay (Blue Nile) basin of the Ethiopian Highlands. Our study generates the first depth- and hillslope-distributed soil water retention curves, textural profiles and measures of hydraulic conductivity for the region. We provide guidance into preferred pedotransfer functions (PTFs) and their sensitivity to clay fraction. Hydrological processes associated with the observed vertical profiles and variations on them were simulated with the Hydrus-2D software package, revealing that dominant runoff generation mechanisms were sensitive to the vertical organisation of soil texture, particularly at depths of 30cm or more below the soil surface for soil profiles that have well-drained surface soil textures.

This suggests that current practices of evaluating soil properties based on surface texture only is insufficient for understanding hillslope hydrology and mitigating soil erosion in these regions. In regions where comprehensive soil hydraulic profile data is not available, our study quantifies the uncertainties in both PTFs and hydrological fluxes due to variation of soil profile texture present; these can aid decision makers in data collection and accounting of errors for the intended application of interest.

This research is supported by the Institute of International Studies Pre-Dissertation Research Grant at University of California.

Soil sampling in Debre Mawi: a) Clay, b) Silty Clay and c) Saprolite.



Map of the study area and sampling locations.

Recalibration of existing pedotransfer functions to estimate soil bulk density at a regional scale

Project team: Professor Habib Khodaverdiloo[2] (project leader; h.khodaverdiloo@urmia.ac.ir), Dr Amir Bahrami[3], Dr Mehdi Rahmati[4], Professor Harry Vereecken[5], Associate Professor Mirhassan Miryaghoubzadeh[2], Associate Professor Sally Thompson[1]

Collaborating organisation: [1]UWA; [2]Urmia University, Orūmīyeh; [3]Tarbiat Modares University, Iran; [4]University of Maragheh, Iran; [5]Institute of Bio- and Geosciences: Agrosphere (IBG-3), Germany

Soil bulk density (ρ_b) is an important indicator of soil quality, productivity, compaction and porosity. Despite its importance, ρ_b is often omitted from global datasets due to the costs of making many direct ρ_b measurements and the difficulty of direct measurement on rocky, sandy, very dry, or very wet soils. Pedotransfer functions (PTFs) are deployed to address these limitations. Using readily available soil properties, PTFs employ estimator equations to fit existing datasets to estimate properties like ρ_b. However, PTF performance often declines when applied to soils outside those in the training dataset. Potentially, recalibrating existing PTFs using new observations would leverage the power of large datasets used in the original PTF derivation, while updating information based on new soil observations.

Here, we evaluate such a recalibration approach for ρ_b estimation, benchmarking its performance against two alternatives: the original, uncalibrated PTFs, and novel, local PTFs derived solely from new soil observations. Using a ρ_b dataset of $N = 360$ total observations obtained in West Azerbaijan, Iran, we varied the local dataset size (with $N = 15$, 30, 60, and 360) and recalibrated four existing PTFs with these data. Local PTFs were generated based on stepwise multiple linear regression for the same datasets. The same PTFs (original, recalibrated, and local) were also applied to the study area, and the resulting ρ_b estimates were compared with the global SoilGrids dataset. Recalibration of PTFs reduced errors relative to the original uncalibrated PTFs; for instance, the NSE increased from −22.07 to 0.30 (uncalibrated) to 0.20–0.41 (recalibrated), and RMSE decreased from 0.12 to 0.60 $Mg\,m^{-3}$ (uncalibrated) to 0.10–0.13 $Mg\,m^{-3}$ (recalibrated). The recalibrated PTFs performance was comparable to or better than local PTFs applied to the same data. Recalibration of existing PTFs with local/regional uses provides a viable alternative to the use of global datasets or the development of local PTFs in data-scarce regions. Highlights of this research project include:

a) Existing global PTFs were calibrated and tested using a small dataset for local utilisation,
b) Several new local PTFs were also developed using the same datasets, and
c) Recalibration of existing global PTFs is comparable to or more accurate than developing new PTFs.

Lower Kent River – studying river response to land clearing and landscape salinisation in southwestern Australia.

Whiteman Park for the Recharge Estimation Collaboration project.

Centre for Water and Spatial Science

Project team: Associate Professor Sally Thompson[1] (co-director; sally.thompson@uwa.edu.au), Associate Professor Nik Callow[1] (co-director; nik.callow@uwa.edu.au), Associate Professor Matt Hipsey[1] (co-director; matt.hipsey@uwa.edu.au), Associate Professor Bryan Boruff[1], Professor Michael Douglas[1], Professor Samantha Setterfield[1], Professor Jason Beringer[1], Dr Natasha Pauli[1], Dr Caitlin Moore[1], Dr Sharyn Hickey[1], Dr John Duncan[1], Dr Sarah Bourke[1], Dr Jim McCallum[1], Dr Qiaoyun Xie[1]

Collaborating organisation: [1]UWA

The Centre for Water and Spatial Science (CWSS) was established in 2021. The Centre unifies leading water and geospatial science researchers across schools including the UWA School of Agriculture and Environment, and the School of Earth Sciences and Engineering (School of Civil, Environmental and Mining Engineering). CWSS provides evidence-based solutions to complex water and spatial challenges. Through partnerships across industry, government, and non-governmental organisations, CWSS provides science-based solutions locally, regionally, nationally, and internationally.

PhD candidate Reza Bakhshoodeh's project on the thermal performance of green facades at Bentley Primary School.

The Centre for Water and Spatial Science's mission is to 'Seek new water knowledge in a changing climate'. CWSS is dedicated to understanding and addressing evolving environmental challenges.

The CWSS focuses on five themes:

- Water in a Changing Climate
- Resilient Landscapes
- Catchment to Coasts
- Data Driven Discovery and Spatial Analytics
- Research Teaching Nexus

The changing climate challenges our ability to manage food and water security, economic wellbeing, and the environment. Understanding catchments, rivers, aquifers, estuarine systems, and coasts, and how they respond to the changing climate must be at the forefront of responding to this challenge. Spatial data, satellite data, drones, and translational research with industry underpin our ability to gain a deeper understanding of these issues.

This research is supported by UWA.

Farm dams were full after the 2022 season, but challenges to have fit-for-purpose water with low turbidity. Photos: Roberto Lujan Rocha

WaterSmart Dams – Making dams work again

Project team: Associate Professor Nik Callow[1] (project leader; nik.callow@uwa.edu.au), Dr Richard George[3], Daniel Kidd[4], Associate Professor Sally Thompson[1], Associate Professor Matt Hipsey[1], Dr Caitlin Moore[1], Dr Bonny Stutsel[1], Dr John Duncan[1], Storm Findlay Cooper[1], Associate Professor James Fogarty[1], Professor Ross Kingwell[1], Giles Knight[1], Roberto Lujan Rocha[1,2], Maddy Wylie[5], Andrew Richie[6], Adele Scarfone[7], Glenice Batchelor[8]

Collaborating organisations: [1]UWA; [2]Australian Herbicide Resistance Initiative (AHRI); [3]DPIRD; [4]Grower Group Alliance (GGA); [5]Fitzgerald Biosphere Group; [6]Compass Ag Alliance; [7]Southern Dirt; [8]Merredin & Districts Farm Improvement Group

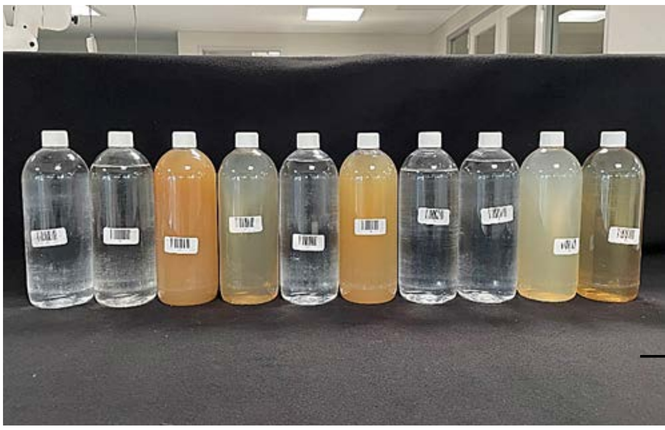
This two-year project aims to develop knowledge and water planning tools for farmers who need their dams to work in all years and be able to make water investment decisions with confidence. The project will involve 12 core demonstration sites, building farm-based water planning tools, workshops, field days and industry training. The project will investigate solutions including renovating existing dams, building new dams, and implementing evaporation suppression and runoff technologies.

The GGA through the South-West WA Drought Resilience Adoption and Innovation Hub, will collaborate with DPIRD and UWA, leveraging their existing work and prior investment in this field as well as four grower group project partners including Compass Agricultural Alliance (Darkan), Southern Dirt (Kojonup), Merredin and Districts Farm Improvement Group (Merredin) and the Fitzgerald Biosphere Group (Jerramungup). WaterSmart Dams builds on the existing WaterSmart Farms program – a collaborative DPIRD-designed program researching sustainable groundwater supply options using on-farm desalinisation technology.

In 2022, the WaterSmart Dams project team launched a survey to understand how poor water supply and quality are affecting growers in dry years and identify which water saving and capture methods are already being adopted beyond reliance on traditional dams and catchments in paddocks. The survey closed in October 2022.

Project technical lead Associate Professor Nik Callow said the initial results showed that 93 per cent of growers surveyed so far have invested in improving water supply or quality in the last decade. The survey also indicated that growers are seeking better information on cleaning out dams and stopping leaky dams and are looking for opportunities to view demonstration sites that showcase HDPE plastic catchments and efficient and well-maintained roaded catchments. Another trend noted among survey participants was the rejuvenation of existing dams or building larger dams with a capacity of more than 20 mL to get through the drier years.

This project is jointly funded through Australian Government's Future Drought Fund and DPIRD.



Variability in farm water samples collected as part of the WaterSmart Dams project.

Evapotranspiration partitioning based on leaf and ecosystem water use efficiency

Project team: Liuyang Yu[2], Associate Professor Sha Zhou[3], Professor Xining Zhao[2] (project leader; gaoxuerui666@163.com), Professor Xiaodong Gao[2], Kongtao Jiang[2], Associate Professor Baoqing Zhang[4], Professor Lei Cheng[5], Dr Xiaolin Song[2], Hackett Professor Kadambot Siddique[1]

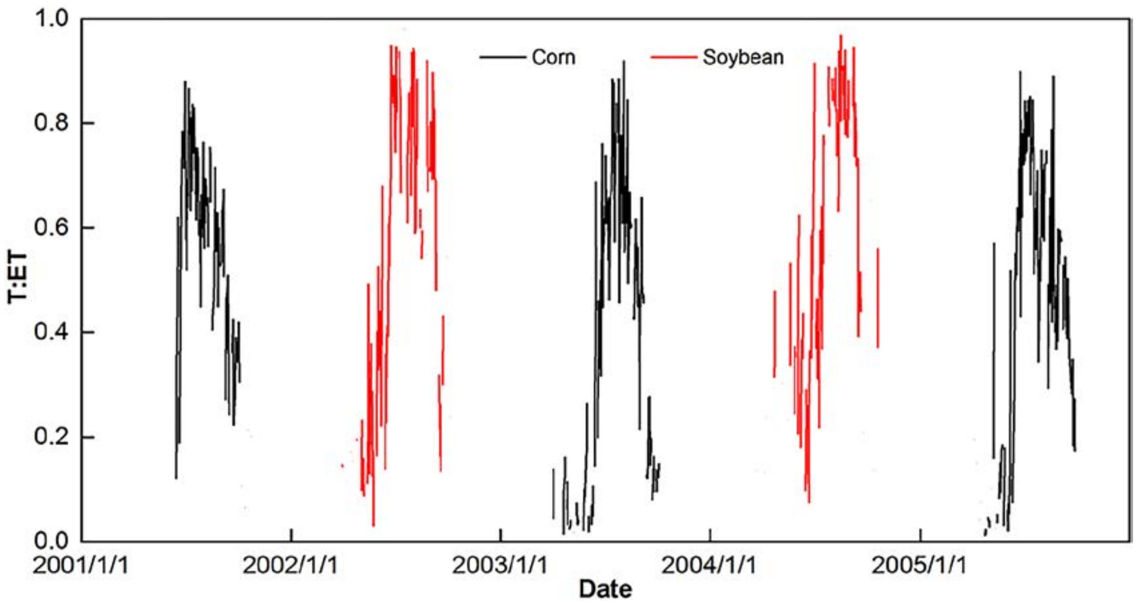
Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]Beijing Normal University, China; [4]Lanzhou University, China; [5]Wuhan University, China

Partitioning evapotranspiration (ET) into evaporation (E) and transpiration (T) is essential for understanding the global hydrological cycle and improving water resource management. However, ecosystem-level ET partitioning remains challenging.

Here we proposed a novel ET partitioning method that uses the unified stomatal conductance model to estimate *T*:ET by calculating the ratio of the ecosystem water use efficiency (WUE_{eco}) to leaf WUE (WUE_{leaf}) using half-hourly flux data. The WUE_{leaf} values estimated by the unified stomatal conductance model agree with an independently measured ratio of hourly photosynthetic rate to *T* rate (R^2 = 0.69). The sensitivity of *T*:ET to the key parameter g_1 varied among different plant functional types (PFTs), but the *T*:ET variations for each PFT were all controlled within 20 per cent when g_1 altered within its 95 per cent confidence interval. The mean annual *T*:ET was highest for evergreen broadleaf forests (0.63), followed by deciduous broad forests (0.62), grasslands (0.52), evergreen needleleaf forests (0.43) and woody savannas (0.40). C_3 croplands had higher *T*:ET (0.65) than C_4 croplands (0.48). Seasonal variations in *T*:ET varied across PFTs and the leaf area index explained about 50 per cent of the variation in seasonal *T*:ET.

Our method is not only consistent with other three EC-based methods: Z16, N18, and L19 (R = 0.92, 0.94, and 0.68), but also shows high correlations to sap flow-based *T* (R = 0.70) at three different forest sites. The method developed in this study provides a feasible and universal approach for ET partitioning of global EC sites, improving the understanding of ecosystem *T* characteristics across climates and PFTs.

This research is supported by the National Natural Science Foundation of China, Shaanxi Innovative Research Team for Key Science and Technology, CAS 'Youth Scholar of West China' Program, Shaanxi Province key R&D plan, and Chinese Universities Scientific Fund.



Seasonal and interannual variations in transpiration: evapotranspiration at the daily scale for five consecutive years of rotation between corn and soybean cultivation.

One of the partners in the Australia-India Water Centre consortium, the Indian Institute of Technology, Guwahati.

The Australia India Water Centre

Project team: Professor Arumugam Sathasivan[2] (project leader; s.sathasivan@westernsydney.edu.au), Adjunct Professor Susana Neto[1], Adjunct Professor Jeff Camkin[1], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Western Sydney University; Queensland University of Technology; Flinders University; The University of Melbourne; University of New South Wales; University of Wollongong; Indian Institute of Technology Guwahati; Banaras Hindu University, India; GB Pant University of Agriculture & Technology, India; Indian Institute of Science, India; Indian Institute of Technology, India; India Institute of Technology, India; Indian Institute of Information Technology India; Jawaharlal Nehru Technological University, India; JSS Science and Technology University, India; Maharana Pratap University of Agriculture & Technology, India; National Institute of Technology India; National Institute of Hydrology, India; SV National Institute of Technology, India University of Agricultural Sciences, India

The Australia India Water Centre (AIWC) is a virtual joint centre established by a consortium of Australian and Indian universities, research institutions and water businesses to promote cooperation and collaboration in water research, education, training, and capacity building. The Centre provides a platform for long-term partnerships and dialogue between Australian and Indian water researchers, policymakers, industry partners and non-governmental organisations to work together for a common goal, 'United Nations SDG 6 – Ensure availability and sustainable management of water and sanitation for all'.

The AIWC is focused on collaboration in transdisciplinary research, capacity building and knowledge and technology transfer, particularly on aspects of water and food security, safe drinking water supplies, river health, water-energy-food nexus, water for liveable cities and other related facets of mutual benefits to Australia and India through the following key activities:

a) Develop tools and techniques for improving management of surface and groundwater resources (including springs, stormwater, wetlands, lakes, and coastal reservoirs), water policy and governance and resilience and adaptation to climate change, while supporting the water missions and initiatives of the two countries,
b) Establish a joint online master's program in 'Transdisciplinary Water Resources Management,'
c) Conduct capacity building and training programs for government department staff, policy makers, students, NGOs and industry personnel through short courses, workshops, conferences, and webinars.
d) Promote transdisciplinary research, socio-economic and cultural aspects, woman empowerment, citizen science and community engagement in water resources management, and
e) Support water expertise of the Centre partners for international engagement, networking, and people-to-people contacts.

Launched in November 2021, the India Young Water Professionals Program is being delivered by a consortium of the Australian Water Partnership, the Government of India Ministry of Jal Shakti, and the AIWC. The program is unique compared to typical capacity building and training programs, with about 70 percent of the program focused on project-based learning with real-world situations and clients. The remainder will be through coaching and online workshops.

UWA adjunct professors Susana Neto and Jeff Camkin mentored young Indian professionals as part of the first year of the Indian Young Water Professionals program in 2022. India faces enormous water challenges, now and into the future, and building the capacity to address real-world situations will be critical to addressing those challenges. This partnership between India and Australia is making an important contribution to addressing that need by sharing knowledge, skills and experience, and helping build confidence in Indian young water professionals who will have to face those practical challenges.

This research was initially funded through the Australian Government. The Government of India has committed to funding the next phase.

Diversified crop rotations reduce groundwater use and enhance system resilience

Project team: Shiquan Wang[2,3], Jinran Xiong[2], Boyuan Yang[2], Dr Xiaolin Yang[2,3] (project leader; yangxiaolin429@cau.edu.cn), Professor Taisheng Du[2,3], Professor Tammo Steenhuis[4], Hackett Professor Kadambot Siddique[1], Professor Shaozhong Kang[2,3]

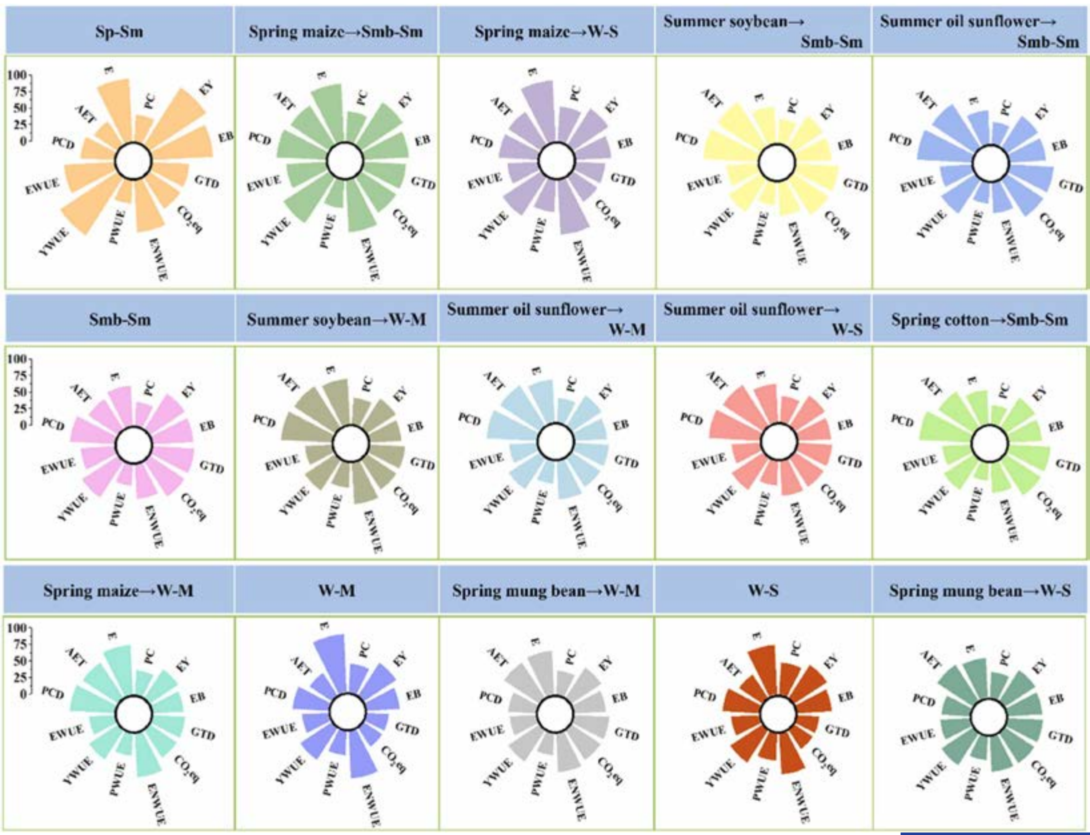
Collaborating organisations: [1]UWA; [2]China Agricultural University, China; [3]National Field Scientific Observation and Research Station on Efficient Water Use of Oasis Agriculture in Wuwei of Gansu Province, China; [4]Cornell University, USA

Agricultural intensification has increased crop productivity but simplified production and reduced cropping system diversity. In recent decades, the intensified wheat-maize rotation in the North China Plain has sharply decreased the groundwater table, with associated environmental and biodiversity issues. Understanding whether increasing cropping system diversity stabilises productivity, improves resilience, and reduces adverse environmental impacts is critical.

This study quantified the water requirements of nine staple crops from 1960 to 2020, established 15 alternative crop rotations, and evaluated the resilience of each rotation in the Cangzhou area, a typical groundwater deletion funnel area. The results showed that reducing cropping density (harvests per year) from 2 to 1.5 decreased the average annual water requirement and irrigation demand by 14 per cent and 33 per cent, respectively. Summer soybean alternated with maize and rotated with wheat did not reduce groundwater use but increased profitability and protein production. Spring mung bean–summer millet-based multi-rotations had higher precipitation coupling degrees (8 per cent in wet years, 17 per cent in normal years, and 56 per cent in dry years) and profitability (1.1–2.4 times) than the wheat–maize rotation. The spring potato–summer millet rotation in one year had the greatest profitability, the highest equivalent yield to wheat, and the highest water use efficiency (WUE), while spring maize rotated with winter wheat–summer soybean performed best for protein content, energy output, and WUEs.

This study identified 11 alternative rotations with a higher comprehensive evaluation index than the conventional wheat–maize rotation based on entropy-TOPSIS considering 12 indicators. Spring mungbean is not suitable for inclusion in the crop rotation when solely cultivated in one year due to mismatched rainfall. Beyond wheat and maize, soybean, millet, and potato are promising crops for innovative multi-year multi-crop rotations to enhance crop diversification, maximise system outputs, and minimize groundwater and energy depletion. This study's analysis could be extended to develop robust and diverse crop rotations with multiple co-benefits in other water-stressed agricultural regions.

This research is supported by the National Natural Science Foundation of China, Chinese Academy of Engineering project, and Hebei Province Key Research and Development Program of China.



Multiple objectives analysis of diversified crop rotations at Cangzhou from 2008 to 2020.

Participants at the UPWATER kick-off meeting in Barcelona, Spain, on 29 November 2022. Photo: CSIC

UPWATER: A new EU-funded project to prevent the release of chemicals to groundwater

Project team: Dr Enric Vázquez-Suñé[2] (project leader; enric.vazquez@idaea.csic.es), Adjunct Professor Susana Neto[1], Adjunct Professor Jeff Camkin[1]

Collaborating organisations: [1]UWA; [2]Agencia Estatal Consejo superior de Investigaciones Científicas, Spain; 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; Australian Nuclear Science and Technology Organisation (ANSTO)

A new consortium of 11 organisations across Europe, and two associated organisations from Australia, has been formed specifically for UPWATER. The University of Western Australia, through IOA, is an associate member.

UPWATER commenced in November 2022 and will run for three and a half years, until May 2026. The project is coordinated by the Institute of Environmental Assessment and Water Research (IDAEA-CSIC). This project aims to increase the knowledge about the pollution sources and pathways that impact groundwater quality. This will allow to design effective at-source preventive measures, both technical and non-technical, to reduce the release of pollutants to groundwaters.

The main goal of UPWATER is to assess the effectiveness of different preventive measures (e.g., regulation, governance, and other non-technological measures) to minimise the release of chemicals to groundwater bodies through:

a) Increase of knowledge on the identification, occurrence and fate of pollutants and pathogens in groundwaters with purposely developed cost-efficient passive sampling methods,
b) Development of methods for the identification and quantification of pollution sources,
c) Development of water quality models to simulate the effect of mitigation efforts, and
d) Development of frameworks for risk analysis and impact assessment as well as for the analysis of nontechnological measures for groundwater contamination.

The second goal is to develop and validate the performance of bio-based engineered natural treatment systems designed as mitigation solutions to protect groundwater pollution. The performance of these measures will be evaluated and their scaling-up will be simulated to assess the potential environmental benefits for a broad adoption.

The monitoring, modelling, and mitigation solutions will be validated in case studies in Denmark, Germany and Spain, representing different European climate conditions and a combination of rural, industrial and urban pollution sources.

UPWATER will provide tools and strategies to implement a safe and contaminant-free recharge water into aquifers. The involvement of stakeholders, water agencies, and policy makers using co-creation spaces that will involve citizenship participation will trigger social acceptance and appraisal of the solutions provided in this project.

The project will also 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.

UWA's main role will be to convene one or more workshops to share knowledge and experience on groundwater protection between Australia and Europe. Given his extensive background in water governance, Professor Camkin will also play an important role in the project delivery, with responsibility for guiding the translation of research findings into policy briefs for action at the local, national and EU-level.

This research is supported by Horizon Europe – Clean Environment and Zero Pollution.

Vineyard photographed in autumn in the Margaret River region.

4

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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The latent axillary bud of grapevine is an important structure for seasonal acclimation. The bud develops in the first season and comprises a primordial shoot, including inflorescence primordia.

How do perennial tree crops adapt to changes in seasonality? Genetic tools to control grapevine development

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

Collaborating organisations: [1]UWA; [2]DPIRD; [2]CSIRO Plant Industries (Adelaide)

Despite enormous advances in plant science over the past 50 years, perennial tree crops have been left behind. Our group investigates the control of perennial fruit crop production in different climates. Grapevine is an incredibly 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.

Ascorbate and glutathione are the two most abundant soluble antioxidants in plants. Oxidation and its counter-poise by antioxidants is incredibly important for the growth and vitality of annual crops. Deficiencies in ascorbate or glutathione results in slow and stunted growth and reduced resistance to environmental stress.

This knowledge has been incredibly important for managing germination, dormancy and pre-harvest sprouting in annual crops, but how does it translate to a perennial? We have identified the genes that control synthesis of ascorbate and glutathione in grapevine and have designed tools to knock down their activity.

Our partners in CSIRO Adelaide are developing the transformed lines to be transferred to UWA later this year for functional studies. Further gene targets are being developed in order to build a pipeline of genetic tools to advance understanding of perennial growth seasonality.

This research is supported by UWA, CSIRO Plant Industries (Adelaide) and an ARC Discovery Project grant.

Early shoot development of table grapes in Broome.

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), Professor John Considine[1], Cristina Paez-Quintero[1], Dr Aneta Ivanova[1], Dr Dario Stefanelli[2], Dr Chris Ham[2], Colin Gordon[2], Dr Melanie Ford[2], Aimee Grieves[2], Daniel Grobler[3], Brian Della[3]

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

Enabling table grape production in Northern Australia could replace $80 million imports each year. Table grapes are among the most valuable fruit industries nationally and globally. Presently, Victoria produces nearly 80 per cent national production but capacity to expand is limited. Northern Australia offers potential to expand production and more importantly offers the opportunity to extend the season of available fruit, replacing imports during June to November.

This project, funded by the CRC for Developing Northern Australia, is working with partners at DPIRD and Fruitico/Fresh Produce Group, to develop new strategies to enable viable production in Broome and similar tropical climates.

Internationally, Brazil and other tropical countries are successfully producing table grapes up to three cycles per year. This requires vastly different management practices to contemporary production. Grapevine was domesticated in temperate/Mediterranean climate and contemporary management requires seasonal changes in daylength and temperate for orderly production cycle. In Northern Australia, tropical and subtropical climates lack these seasonal cues. On one hand this removes environmental limitations. On the other hand, it makes viable production very challenging. The current yield penalty in Carnarvon and Broome is more than 50 per cent.

This project will use agronomic strategies, and work with industry to explore different varieties and management techniques to enable viable and sustainable table grape production in Broome and other locations in Northern Australia.

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

UWA Associate Professor Michael Considine among grapevines.

Vineyard Floor Management Project

Project team: Dr Joanne Wisdom[1,2] (project leader; joanne.wisdom@gga.org.au), Associate Professor Nik Callow[1], Daniel Kidd[2], Dr Caitlin Moore[1], Storm Findlay Cooper[1]

Collaborating organisations: [1]UWA; [2]Grower Group Alliance (GGA); DPIRD; Wines of Western Australia; Agricultural Produce Commission (Table Grapes)

Regular grape testing and soil analysis are critical components of effective vineyard management, and researchers from UWA are using advanced technologies such as soil probes, drones, and thermal imaging to monitor vine health and optimise farming practices in the Swan Valley, Cape Mentelle, and Plantagenet regions. Starting in 2022, UWA researchers visited the Swan Valley every week to test grapes for maturity and sugar content, which can provide valuable insights into grape quality and optimal harvest times. Analysing and comparing soil density differences between vines that have been subjected to different levels of machinery use, growers can make informed decisions about vineyard management practices that can promote healthy vines and improve overall grape quality.

Through continued investment in research and development, UWA researchers and growers can work together to meet the challenges posed by climate change and other stressors. Advanced technologies and regular monitoring of vine health and soil quality are crucial for ensuring the long-term sustainability of the wine industry in Western Australia and continuing to contribute to the region's economy.

On 30 November 2022, Dr Caitlin Moore attended a table grape industry field day in the Swan Valley to hear how cover cropping and mulching can benefit vineyard water use (cover cropping and drone thermal imaging).

This research is supported by UWA, DPIRD and GGA.

Grapes pictured ripening on the vine. This project aims to implementing improve vineyard floor management for premium grape production.

Monitoring device set-up in a Western Australian vineyard.

Insight into the interaction between light and colour development in apples

Project team: Associate Professor Michael Considine[1,3] (project leader; michael.considine@uwa.edu.au), Zhe Gao[1,2], Dr Dario Stefanelli[3], Nardia Stacy[4]

Collaborating organisations: [1]UWA; [2]Inner Mongolia University of China; [3]DPIRD; [4]Pomewest

Fruit colour is a crucial component of apple production, which underpins market quality requirements and consumer preference. Variety ANAPB 01, for example, must satisfy strict colour requirements to be marketed as a Bravo® premium apple. This project was led by an international scholarship recipient Zhe Gao (on a one-year research visit) to undertake foundation research to assist apple growers to improve fruit colour – a significant driver of fruit quality and profitability. Mr Gao, from Inner Mongolia University of China, has a background in analysis of plant flavonoid components.

The project aimed to lay the groundwork to better understand possible thresholds at which growers could take action to improve colour, earlier in the season. It will provide a valuable insight into the interaction between light and colour development in apples. The research will examine the quantity and quality of the apple colour, how colour changes, what is driving those changes and the chemical composition of colour. The field trial component of the research will involve the use of bags to cover the developing fruit, to simulate shade variations, to measure the physiological colour responses to light exposure. The biochemical analysis will take apple production to the next level and inform discussion about management intervention options that could improve orchard management, yields and quality. A better understanding of the physiological development of apple colour, together with emerging technology will enable the apple industry to refine orchard management. Growers will be able to identify the optimum time – earlier in the season – to intervene to improve fruit colour, removing the need to wait to pick fruit and maximising orchard potential.

The initiative builds on a one-year research project by DPIRD and Pomewest, a sub-committee of the Agricultural Produce Commission, that evaluated the use of monitoring and mapping technology to refine orchard management. The project examined technology that uses Light Detection and Ranging (LiDAR) remote sensing data and digital images to map and monitor orchard growth, developed by Australian company Green Atlas, with in-kind support from local supplier Aero Vines.

This research is supported by UWA, DPIRD, Pomewest, and the China Scholarship Council Program.

Zhe Gao photographed at UWA's Crawley Campus with two red apples.

A beekeeper uses a torch to check for AFD.

Beekeeper experience and training are associated with beneficial practices that prevent the spread of American foulbrood (*Paenibacillus* larvae)

Project team: Charlize van der Mescht[1], Dr Barbara Cook[1] (project leader; barbara.cook@uwa.edu.au), Dr Peter Speldewinde[1], Jessica Bikaun[1,2], James Sheehan[2]

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

Western honey bees are essential for global agricultural and horticultural productivity, yet bee populations are threatened by pests and disease. American foulbrood (AFB) is an uncurable and fatal bacterial disease of the honey bee larvae and is considered to be the worst threat to the Australian beekeeping industry. The only way to limit the occurrence of the disease is to stop its spread through the adoption of good management practices such as limiting the movement of equipment, tools and honey between hives as well as implementing regular hive inspections, honey culture testing, and the use of a barrier management system. A survey of 514 Australian beekeepers was undertaken to investigate to what extent beekeepers are adopting these practices and what factors influence their adoption. Ability to detect AFB was also investigated.

It was found that overall, beekeepers in Australia exhibit good biosecurity practices, with several associated factors influencing this, including training and experience. Formal online training was associated with improved biosecurity practices and a higher ability to identify American foulbrood. However, exposure to disease and disease recognition should be incorporated into face-to-face training to improve these practices and the ability of inexperienced beekeepers. A majority of beekeepers had a high ability to identify AFB. The self-reported and tested ability of beekeepers to recognise AFB was similar, demonstrating that self-reported ability can be used as a proxy of actual ability. Geographic differences in ability and practices may be explained by the higher AFB exposure rate in the east of Australia or by differences in legislation.

This study provides evidence to demonstrate that the mandating of beneficial biosecurity practices is associated with an improvement in biosecurity outcomes, highlighting the importance of policy enforcement.

This research is supported by UWA, DPIRD via donation to the Arjen Ryder Memorial Scholarship, and Royalties for Regions for the contribution to the UWA Agribusiness Connect Masters Research Project Scholarship.

Two glass jars of honey with a wooden honey dipper.

PhD candidate Sylvester Obeng-Darko collecting nectar from flowers for analysis.

Leptospermum polygalifolium flower development beginning approximately 36 h before anthesis (-36 h bud) to flower senescence at day 14.

Unravelling the secrets of nectar production for bioactive honey

Project team: Associate Professor Patrick Finnegan[1] (project leader; patrick.finnegan@uwa.edu.au), Sylvester A. Obeng-Darko[1], Professor Erik Veneklaas[1], Dr Peter Brooks[2], Jean Sloan, Ivan Iozada Lawag, Toby Bird, Shutong Liu, Martin Brown[3], Jenna Ford[3], Renata Lucia Grununnvaldt[3], Simon Williams[3]

Collaborating organisations: [1]UWA; [2]University of the Sunshine Coast; [3]Gather By

Manuka honey, derived from the nectar of *Leptospermum* spp., is famous for its strong bioactivity. The high bioactivity of this honey is due to its methylglyoxal (MGO) content. Methylglyoxal in honey arises from dihydroxyacetone (DHA) in nectar through autocatalyic conversion during honey maturation. That is, DHA is found in floral nectar of *Leptospermum scoparium* and other species of *Leptospermum*, while MGO only appears in honey. Intriguingly, DHA is not a normal plant metabolite. It is not yet certain that DHA in floral nectar is produced by the plant, or if it is produced by another process.

The first objective of this research was to determine the timing of the appearance of DHA in floral nectar of L. *polygalifolium* and L. nitens, species of *Leptospermum* endemic to Queensland, NSW, and Western Australia, respectively. The second objective was to link gene transcript patterns within floral nectaries to DHA appearance in nectar to create a hypothetical plant-derived pathway to explain the appearance of DHA in nectar. The goal was to provide industry with advanced knowledge of key traits to predict DHA appearance in nectar to supply growers and apiarists with management tools to increase DHA levels in nectar, thus increasing MGO levels and bioactivity in mature honey.

Nectar was collected from flowers of wild and cultivated L. *polygalifolium* and wild L. *nitens* across flower life span. Nectar levels of DHA were determined by High Performance Liquid Chromatography. Flowers were collected from L. *nitens* across flower development to determine phosphatase activity and to isolate RNA from samples enriched in nectary tissue. The RNA population was sequenced to generate a transcriptome for L. *nitens*. The transcriptome was used to determine the transcript patterns for the enumerated genes and how these patterns changed as flowers aged.

The appearance of DHA in floral nectar of both L. *polygalifolium* and L. *nitens* followed the profile of total sugar. Both DHA and total sugar concentrations peaked early in flower development, and then declined as flowers aged. The timing, but not the amounts, of DHA and total sugar appearing on L. *polygalifolium* flowers was similar. The timing of peak DHA was earlier in L. *nitens* than in L. *polygalifolium*. The dynamics of the ratio of DHA to total sugar in L. *polygalifolium* indicated that nectar is continually secreted and reabsorbed by flowers in this species. Apiarists now know the best time for bees to forage on L. *polygalifolium* and L. *nitens* flowers to optimise the harvest of DHA.

It was also discovered that other species of Myrtaceae outside of the genus *Leptospermum* accumulate DHA in their nectar. The species identified to accumulate DHA are *Ericomyrtus serpyllifolia* and *Verticordia chrysantha*. This knowledge provides apiarists with alternative opportunities outside the genus *Leptospermum* to harvest nectar that will potentially yield bioactive honey. The objective of this project was to understand the genetic control of *Leptospermum* nectar production and its relationship with DHA appearance so that plant material can be selected and manipulated to optimise production of high-quality nectar.

This research is supported by UWA and the CRC for Honey Bee Products.

Honey flavour profiles: South-west of Western Australia

The mixing of each of the honeys in distilled water prior to tasting.

Project team: Professor Sharon Purchase[1] (project leader; sharon.purchase@uwa.edu.au), Lou Chalmers[2], Dr Kim Feddema[1,3], William Roser, Gabriel Tan[4], Dr Liz Barbour[1]

Collaborating organisations: [1]UWA; [2]Yume Wines; [3]ECU; [4]Origin Coffee Traders; BQUAL

The aim of this project was to generate a list of generic attributes to describe the flavour and aroma profiles of some of the most significant honeys produced in WA. There has been very little work conducted in WA to classify honey flavour profiles to date. As such, it is necessary to draw upon experts from other industries with expertise in tasting and flavour assessment of honeys. Three coffee and wine industry experts (one also with honey expertise) were called upon for this:

- Lou Chalmer is a sommelier, winemaker and consultant with 19 years' experience in the wine, coffee and honey industries.
- William Roser is a sommelier, wine show judge, consultant and hospitality professional with over 20 years' experience.
- Gabriel Tan is a coffee Q grader and winemaker, with 13 years in the specialty coffee industry, including four years international coffee judging experience.

Nine different types of honey were sampled in total. Multiple samples were provided for six of these. The collated results from tastings were recorded. Two samples were provided of Parrotbush honey, yet it was felt there was too much variability in the samples to accurately collate the results, though some of the key parameters have been included in the results, as they were consistent across both samples. There was a high level of consistency amongst honeys where multiple samples were provided, allowing for a high level of confidence in the results. The honey that led to the greatest uncertainty in summarising was Parrotbush, which displayed highly variable aroma and flavour attributes across the two samples provided.

Should the honey industry wish to further pursue honey flavour profiling for marketing and differentiation purposes, it is recommended that a greater number of samples of each honey be tasted to ensure accuracy and consistency. There may also be potential to investigate differences between sites, year and production practices between individual honeys that come from the same floral source, given some of the minor variations between honeys that were otherwise very similar.

This research is supported by UWA, the CRC for Honey Bee Products, and Square Code (renamed Code Forge).

The sommeliers (from the left and sitting down) Gabriel Tan, Lou Chalmer and William Roser. Standing are Dr Kim Feddema, Dr Liz Barbour and Professor Sharon Purchase.

Dark green leafy vegetables, such as kale, are high in vitamin K1.

Higher dietary vitamin K intake is associated with better physical function and lower long-term injurious falls risk in community-dwelling older women

Project team: Dr Marc Sim[1,2] (project leader; marc.sim@ecu.edu.au), Professor Catherine Bondonno[1,2,3], Dr Cassandra Smith[2,3,4], Dr Nicky Bondonno[2,5], Dr Simone Radavelli-Bagatini[2], Dr Lauren Blekkenhorst[2,3], Dr Jack Dalla Via[2], Dr Rachel McCormick[2], Adjunct Associate Professor Kun Zhu[1,6], Adjunct Professor Jonathan Hodgson[1,2,3], Professor Richard Prince[1,2,7], Adjunct Associate Professor Joshua Lewis[1,2,8]

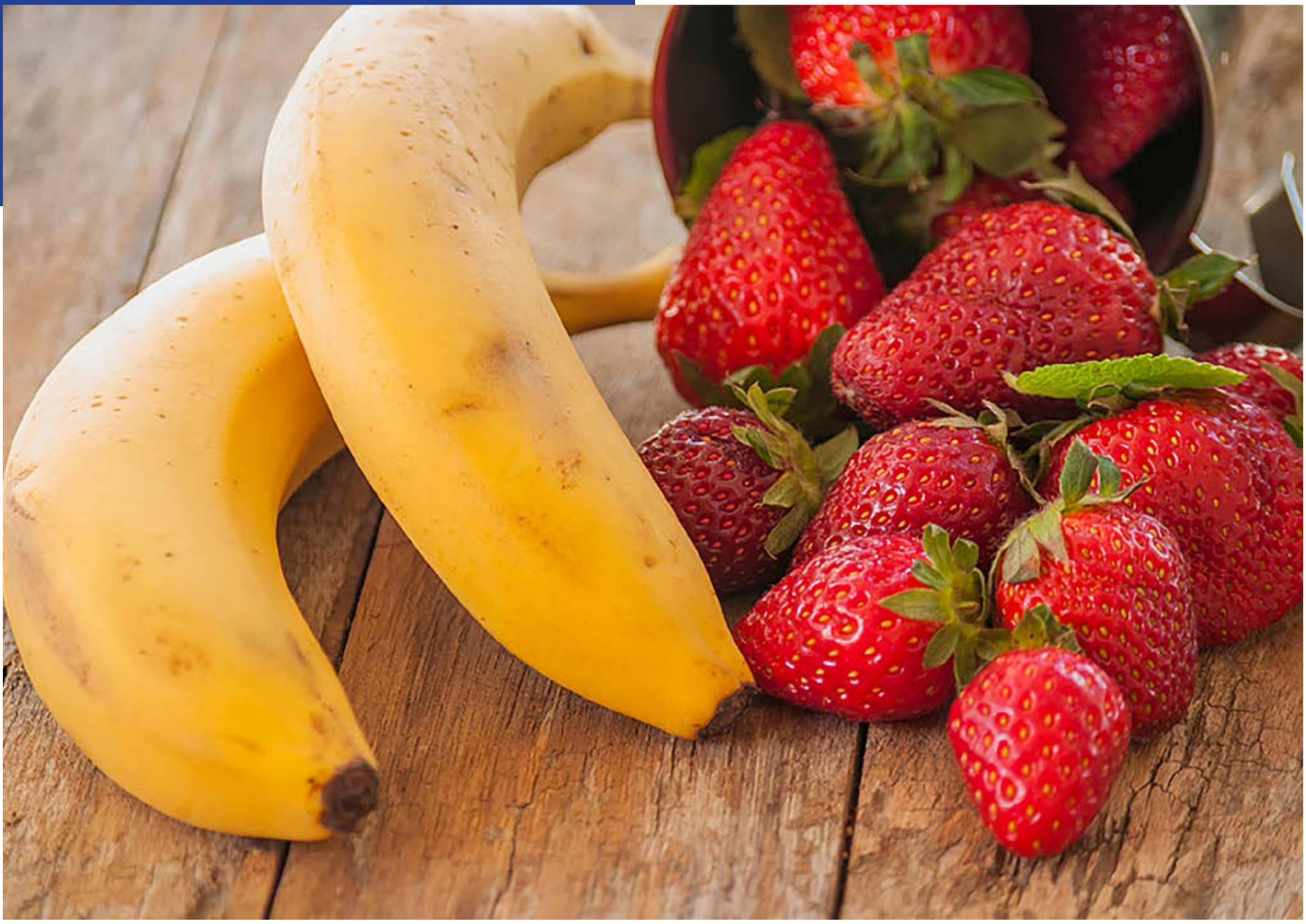
Collaborating organisations: [1]UWA; [2]ECU; [3]Royal Perth Hospital Research Foundation; [3]Victoria University; [4]University of Melbourne and Western Health; [5]Danish Cancer Society, Denmark; [6]Sir Charles Gairdner Hospital, WA; [7]Curtin University; [8]The University of Sydney

In recent years, a potential beneficial role of vitamin K in neuromuscular function has been recognised. However, the optimal dietary intake of vitamin K to support muscle function in the context of falls prevention remains unknown. This collaborative study from UWA and Edith Cowan University (ECU) found that older women who eat a diet rich in vitamin K1 were more than 30 per cent less likely to fracture a bone. The research team looked at the relationship between fracture-related hospitalisations and vitamin K1 intake in about 1400 older Australian women over a 14.5-year period from the Perth Longitudinal Study of Aging Women.

They found that women who ate more than 100mg of vitamin K1 (equivalent to about 125g of dark leafy vegetables) were 31 per cent less likely to have any fracture compared to participants who consumed less than 60mg a day – which is the current recommended intake. Study participants who ate the most vitamin K1 cut their risk of hospitalisation almost in half (49 per cent).

The project provided further evidence of the benefits of vitamin K1, which has also been shown to enhance cardiovascular health. The results are independent of many established factors for fracture rates, including body mass index, calcium intake, vitamin D status and prevalent disease. Basic studies of vitamin K1 have identified a critical role in the carboxylation of the vitamin K1-dependant bone proteins such as osteocalcin, which is believed to improve bone toughness.

This research is supported by Healthway, the Western Australian Health Promotion Foundation and the National Health and Medical Research Council of Australia.



Bananas and strawberries contain far higher amounts of nitrate than previously recognised.

A food composition database for assessing nitrate intake from plant-based foods

Project team: Professor Catherine Bondonno[1,2,3] (project leader; c.bondonno@ecu.edu.au), Dr Liezhou Zhong[2], Dr Lauren Blekkenhorst[1,2,3], Dr Nicola Bondonno[2,4], Dr Marc Sim[1,2,3], Richard Woodman[5], Professor Kevin Croft[1], Associate Professor Joshua Lewis[1,2,3,6], Professor Jonathan Hodgson[1,2]

Collaborating organisations: [1]UWA; [2]ECU; [3]Royal Perth Hospital Research Foundation; [4]The Danish Cancer Society Research Centre, Copenhagen, Denmark; [5]Flinders University, Adelaide; [6]The University of Sydney, NSW

Researchers from UWA collaborated on a project to publish an updated nitrate food composition database for plant-based foods in 2022. The research team from the UWA Medical School and School of Biomedical Sciences, Edith Cowan University, Flinders University, and the University of Sydney found that banana and strawberry contain far higher amounts of nitrate than previously recognised.

The project determined that an up-to-date nitrate food composition database of plant-based foods was lacking. There are both risks and benefits to human consumption of dietary nitrate and nitrite intake. While observational studies have demonstrated a lower risk of cardiovascular disease with higher habitual nitrate intake, there are also possible detrimental effects of high nitrate intake. It is (therefore) imperative to obtain a robust assessment of dietary nitrate intakes and facilitate more empirical evaluation of health implications.

The research team updated and expanded the 2017 vegetable nitrate database by including data published between 2016 and 2021, as well as data on fruits, cereals, herbs, spices, pulses and nuts (from 1980 to 2021). Of the collated nitrate contents for 264 plant-based foods from 64 countries, 120 were obtained from three or more references. Despite substantial variations, leaf vegetables were the top nitrate-containing foods, followed by stem and shoot vegetables, herbs and spices, root vegetables, flower vegetables, tuber vegetables, nuts, fruit vegetables, legume/seed vegetables, and fruits and cereals.

This research is supported by a Department of Health (Western Australia) Merit Award.

Rapid breeding for reduced cooking time and enhanced nutritional quality in common bean

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], Dr Bararyenya Astère[6], Blaise Ndabashinze[7], Julius Mbiu[8], Dr Reuben Otsyula[9], Dr Stanley Nkalubo[10]

Collaborating organisations:
[1]UWA; [2]CIAT-Uganda; [3]CIAT-Kenya; [4]CIAT-Tanzania; [5]RADB Rwanda; [6]EIAR Ethiopia; [7]ISABU Burundi; [8]TARI Tanzania; [9]KARLO Kenya; [10]NaCRRI Uganda

This ACIAR-funded project is led by UWA and brings together crop breeding experts in Australia (at UWA and University of New England) and bean breeders in six partner countries in East Africa. The project goal is 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 selection together with optimal contribution selection (OCS) to accelerate genetic improvement of biofortified and rapid cooking common bean (*Phaseolus vulgaris*). This breeding method is abbreviated in the acronym BRIO. The Alliance of Bioversity International and CIAT (CIAT-Uganda) and the Pan Africa Bean Research Alliance (PABRA) lead the breeding program at CIAT-Uganda and coordinate the project activities in six partner countries in East Africa.

In three years since the project implementation, project has achieved significant progress. Progeny generated from two rounds of crossing were genotyped and evaluated for CKT, Fe, Zn at CIAT-Uganda. Progeny seeds were bulked 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 were used to analyse genomic breeding values for grain yield, CKT, Fe and Zn in the progeny from the two crossing programs. Third round of crossing is in progress, based on the optimised crossing design generated from these breeding values.

In 2022, project has progressed towards transferring the new breeding technology to the East African bean breeders. The project coordinator and research associate from CIAT-Uganda visited UWA and UNE and undertook training in genomic analysis and optimal contributions selection. Training in 2022 continued by video conferencing, with some issues caused by poor connections. The project team is looking forward to face-to-face meetings in 2023.

Partner countries have started using data shared through BMS for selecting progeny for further testing in their region and to advance as potential new varieties within their preferred market classes. Subsequently, new bean varieties will be released into relevant markets in east Africa through the CIAT-PABRA networks and with the involvement of African farmers in participatory variety selection.

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

Research associate Winnyfred Amongi and plant breeder Roy Odama in CIAT-Uganda screenhouse.

Dried red beans (Phaseolus vulgaris) in a bowl.

Dietary habits in Australian, New Zealand and Malaysian patients with end stage kidney failure: A pre-specified cross-sectional study of the FAVOURED trial participants

Project team: Marguerite Conley[2] (project leader; marguerite.conley@health.qld.gov.au), Professor Anne Barden[1], Dr Andrea Viecelli[2,3], Dr Ashley Irish[1,4], Professor Alan Cass[5], Professor Carmel Hawley[2,3], Dr David Voss[6], Elaine Pascoe[3], Katie Lenhoff[4], Adjunct Professor Kevan Polkinghorne[7,8], Dr Lai-Seong Hooi[9], Dr Loke-Meng Ong[10], Peta-Anne Paul-Brent[3], Professor Peter Kerr[7,8], Professor Trevor Mori[1]

Collaborating organisations: [1]UWA; [2]Princess Alexandra Hospital, Queensland; [3]University of Queensland; [4]Fiona Stanley Hospital, WA; [5]Charles Darwin University; [6]Middlemore Hospital, New Zealand; [7]Monash Medical Centre, Victoria; [8]Monash University; [9]Hospital Sultanah Aminah, Malaysia; [10]Penang Hospital, Malaysia; FAVOURED Trial Investigator Team

To our knowledge, this study is the first to examine dietary intakes of key food groups in a large cohort of Australians, New Zealanders and Malaysians with advanced kidney disease. This observational substudy showed that our ANZ and Malaysian cohort consumed low levels of fruit and vegetables but did follow a number of important dietary and lifestyle recommendations that associate with a healthy lifestyle. The majority did not add salt to food at the table, they removed skin from chicken and fat from red meat before eating, and they kept discretionary food intake to one to three times per week. Most were former or non-smokers, they did not currently drink alcohol and they engaged in some form of weekly exercise. Our findings show significant regional variation in dietary intakes of fruit, vegetables, animal proteins and alcohol. Possible explanations for the differences in dietary habits likely reflect cultural and economic differences between countries because the type of food that is most available and affordable is a major determinant of a person's dietary intake.

The present study provides an important overview of the dietary habits of people from Australia and New Zealand (ANZ) and Malaysia with advanced chronic kidney disease (CKD). The data provide insight into areas where specific dietary improvements can be made. In particular, efforts to increase fruit and vegetable intake of this population are needed to improve health and overall mortality risk. Some caution and additional monitoring may be needed when increasing fruit and vegetable intake in those at risk of hyperkalaemia. Our data also highlight the need for further research exploring barriers to meeting the recommended dietary intakes.

Key points from this study include:

- Dietary management plays an important role in the management of patients with kidney failure.
- Current dietary habits of Australians, New Zealanders and Malaysians with advanced chronic kidney disease have not been adequately investigated.
- Dietary fruit and vegetable intakes were significantly higher in ANZ participants then Malaysian participants.
- Fish consumption was higher in Malaysians compared to ANZ participants.
- The significant regional variation in dietary intake for fruit, vegetables and animal protein likely reflects cultural and economic differences.
- Dietary intakes of both fruit and vegetables were inadequate by national recommendations but similar to the general population in both the ANZ and Malaysia cohorts.
- Barriers to meeting recommended dietary intakes require further investigation.

This research is supported by the NHMRC of Australia Project Grant, Amgen Australia Pty Ltd and Mylan EPD (formerly Abbott Products Operations AG).

Fruit and vegetable intake plays an important role in the management of advanced chronic kidney disease.

New alternatives from sustainable sources to wheat in bakery foods: Science, technology, and challenges

A variety of gluten-free flours including corn, rice, chickpea, buckwheat, almond, oat and quinoa.

Project team: Shahida Anusha Siddiqui[2,3], (project leader; s.siddiqui@ dil-ev.de) M. M. Chayan Mahmud[4], Dr Gholamreza Abdi[5], Dr Uracha Wanich[6], Dr Muhammad Qudrat Ullah Farooqi[1], Dr Natwalinkhol Settapramote[7], Dr Sipper Khan[8], Dr Sajad Ahmad Wani[9]

Collaborating organisations: [1]UWA; [2]Technical University of Munich Campus Straubing for Biotechnology and Sustainability, Germany; [3]German Institute of Food Technologies, Germany; [4]Deakin University, Victoria; [5]Persian Gulf University, Iran; [6]Rambhaibarni Rahjabhat University, Thailand; [7]RaJamangala University of Technology Isan Surin Campus, Thailand; [8]University of Hohenheim, Germany; [9]Islamic University of Science and Technology, India

Ongoing research in the food industry is striving to replace wheat flour with new alternatives from sustainable sources to overcome the disease burden in the existing population. Celiac disease, wheat allergy, gluten sensitivity, or non-celiac gluten sensitivity are some common disorders associated with gluten present in wheat.

These scientific findings are crucial to finding appropriate alternatives in introducing new ingredients supporting the consumer's requirements. Among the alternatives, amaranth, barley, coconut, chestnut, maize, millet, teff, oat, rye, sorghum, soy, rice flour, and legumes could be considered appropriate due to their chemical composition, bioactive profile, and alternatives utilization in the baking industry. Furthermore, the enrichment of these alternatives with proper ingredients is considered effective. Literature demonstrated that the flours from these alternative sources significantly enhanced the physicochemical, pasting, and rheological properties of the doughs. These flours boost a significant reduction in gluten proteins associated with food intolerance, in comparison with wheat highlighting a visible market opportunity with nutritional and organoleptic benefits for food producers.

New alternatives from sustainable sources to wheat in bakery foods as an approach that affects human health. Alternatives from sustainable sources are important source of nutrients and bioactive compounds. Alternatives from sustainable sources are rising due to nutritional and consumer demand in bakery industry. New alternatives from sustainable sources improve physicochemical, pasting, and rheological properties of dough. Non-wheat-based foods from non-traditional grains have a potential to increase consumer market acceptance.

This research is supported by UGC and the D.S. Kothari Fellowship.

The UWA Aviation Lab is developing low-cost drones for novel purposes, such as surveying crop health and yield.

5

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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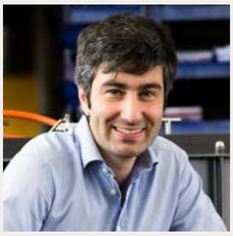

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The black soldier fly larvae feast on waste matter.

Closing the loop: Black soldier fly technology to convert agriculture waste

Project team: Dr Sasha Jenkins[1] (project leader; sasha.jenkins@uwa.edu.au), Associate Professor Marit Kragt[1], Dr Fiona Dempster[1], Associate Professor Fay Rola Rubzen[1], Dr Ian Waite[1], Dr Jen Middleton[1], Hackett Professor Kadambot Siddique[1], Professor Megan Ryan[1], Associate Professor Andrew Guzzomi[1], Dr Talitha Santini[1], Luke Wheat[2], Sofia Katzin[2], Adjunct Professor David Cook[1], Dr Matthew Redding[3], Dr Vandana Subroy[1], Daniel Kidd[1], Dr Andrew Youssef[1], Dr Gerelee Enkhbat[1], Sun Kumar Gurung[1], Audrey Tascon[1], Tamara Harold[1], Janine Price[4], Lachlan Pearson[4] and Peter Scott[4]

Collaborating organisations: [1]UWA; [2]Future Green Solutions; [3]QLD Department of Agriculture and Fisheries; [4]Scolexia Pty Ltd

This project investigated black soldier fly (BSF) technology as a sustainable and profitable management solution for livestock wastes. The project explored how to convert low-value agricultural waste products into high quality, innovative fertilisers and soil improvers that are safe to handle, store, transport and apply. The project also aimed to overcome obstacles to technology adoption and support early adopters by engaging policy makers and farmers in research activities.

In 2022, the research team finished all research activities and submitted the final report to the funding body. The research found that manure derived insect extracts are a good source of nitrogen (N) and phosphorous (P) and the resulting fertiliser formulation can outperform commercial synthetic fertiliser (such as urea and DAP). In a series of pot trials, it was found that manure derived BSF frass can also be used as an effective soil improver that can increase organic C and mineral N retention in soils, raise soil pH (liming effect), improve soil function, structure, stability and resilience to soil constraints (acidic soils, drought), increase the occurrence of plant growth-promoting rhizobacteria and enhance plant growth.

Australian farmers (including livestock producers, dairy farmers, and grain and horticulture growers) had positive opinions towards BSF technology and products and were interested in using the technology or products on their farms. Based on generalised processing and product information, no regulatory barriers exist to the reuse and adoption of manure derived frass as a fertiliser or soil conditioner in Australia. No major behavioural barriers to adopting BSF technology or BSF derived products on farms were identified.

This project has identified several benefits of using BSF technology to process agricultural wastes, which is of relevance to our industry stakeholders. Compared to raw livestock manures, BSF technologies that treat agricultural waste were found to:

- Reduce waste volume by up to 80 per cent over a 19-day period,
- Reduce transportation, application and handling costs,
- Produce a more stable product with limited odour,
- Reduce greenhouse gas emissions (31 per cent reduction for CO_2 and 53 per cent reduction for N2O),
- Reduce prevalence of some bacterial pathogens (99, 95 and 30 per cent reduction in faecal coliform counts for piggery, chicken and dairy manure, respectively), and
- Reduce between 90 and 100 per cent of stable fly (pest) emergence.

A final report summary is available online for public distribution. The researchers are writing up technical reports and academic peer reviewed journal articles that will be published in 2023. As these become available, they will be located on the BSF project website.

This research is supported by the Australian Department of Agriculture and Water Resources, Australian Pork Ltd, Dairy Australia, AgriFutures Australia, Australian Eggs, Australian Meat Processing Corporation, Future Green Solutions, and QLD Department of Agriculture and Fisheries.

PhD student Sun Kumar Gurung attends to his glasshouse experiment.

Close-up of an adult black soldier fly.

Members of the CEI:AgER research team and special guests at the launch event.

Centre for Engineering Innovation: Agriculture & Ecological Restoration

Project team: Associate Professor Andrew Guzzomi[1] (project leader; andrew.guzzomi@uwa.edu.au), Associate Professor Michael Walsh[1], Dr Todd Erickson[1,2], Hannah Demerise[1], Trent Mahony[1], Dr Carlo Peressini[1], Dr Monte Masarei[1], Dr Wesley Moss[1], James Boyle[1], Lee Hunt[1], Yvonne Zago[1], John Yaxley[1], Monica Rothwell[1], William Richards[1], Stephanie Lye[1], Eve McCallum[1], Ruby Wiese[1]

Collaborating organisation: [1]UWA

In its first 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 built 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 2022 include:

- CEI:AgER founding Director Associate Professor Andrew Guzzomi sat on the panel for the WA Innovator of the Year competition in May.
- Two postgraduate students were awarded AW Howard Fellowship funds – PhD candidate (now complete) Dr Wesley Moss and Honours student Ruby Wiese.
- In June, Dr Carlo Peressini and Associate Professor Andrew Guzzomi volunteered to work with school students on their 'design and build' competition at the Perth Science and Engineering Challenge.
- The first official CEI:AgER three-day road trip included visits to three WA farms: Spring Park Farms in Mullewa, McAlpine Farm in Dalwallinu, and Lance Turner's Goodlands farming operation.
- The Hon Minister Dawson official opened CEI:AgER in September
- The Centre participated in the 2022 Shenton Park Field Station Open Day in September – the first public open day held at the site in 10 years.
- In late 2022, CEI:AgER hosted the Grower Group Alliance and Farmanco for a site visit and demonstration.

This research is supported by UWA.

CEI:AgER Director Associate Professor Andrew Guzzomi during the team road trip.

Field of sorghum crops in rows.

Mechanical in-crop weed control

Project team: Associate Professor Andrew Guzzomi[1] (project leader; andrew.guzzomi@uwa.edu.au), Associate Professor Michael Walsh[1], Dr Carlo Peressini[1], James Boyle[1], Hannah Demerise[1]

Collaborating organisations: [1]UWA; GRDC; AgMaster; David Nowland Hydraulics, Corrigin Farm Improvement Group; Precision Agronomics Australia; Facey Group; Dalby Rural Supplies

Conservation agriculture is an important part of sustainable farming and has been embraced by farmers across Australia. However, in order to practice conservation agriculture when removing weeds in large-scale crops, farmers are currently reliant on herbicides. Due to this reliance on herbicides, many small-seeded weed species are becoming increasingly herbicide resistant. 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 is based at CEI:AgER at the UWA Shenton Park Field Station and is funded by the Department of Agriculture, Fisheries and Forestry. It aims to develop a targeted tillage control system for use in-crop in large-scale row-crop farming systems.

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

Benchmarking the current state-of-the-art Horwood Bagshaw approach for subclover seed harvesting.

Building new technologies for sustainable and profitable sub clover seed harvesting

Project team: Professor Megan Ryan[1], Associate Professor Andrew Guzzomi[1] (project leader; andrew.guzzomi@uwa.edu.au), Associate Professor Phillip Nichols[1], Dr Ann Hamblin[1], Brad Wintle[1], Hannah Demerise[1], Dr Wesley Moss[1], Yvonne Zago[1], Ruby Wiese[1], Lee Hunt[1], John Yaxley[1], Monica Rothwell[1]

Collaborating organisation: [1]UWA

This project is based at CEI:AgER at the UWA Shenton Park Field Station.

Subterranean clover (or sub clover) is the world's most widely grown annual pasture legume and is particularly important in southern Australia, where it is considered the backbone of 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 Horwood Bagshaw (HB) suction harvester, currently used to harvest sub clover seed, is based on 1950s technology. HBs have not been manufactured in over 30 years and many in operation are over 50 years old. While effective at collecting and cleaning seed, HBs are slow, labour intensive and generate soil erosion and degradation. Due to the relatively small size of the industry, manufacturers are not incentivised to develop new technologies. Overcoming the economic, environmental and social pressures facing the seed production industry requires new seed harvesting solutions and the development of new technologies to ensure the future supply of sub clover seed.

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 Victoria to address seed production issues. The project will leverage technologies from other industries to develop farm-ready solutions that can increase seed harvesting efficiency and reduce negative environmental impacts.

This research is supported by UWA and AgriFutures Australia.

Adapting peanut harvesting approaches for subclover.

Monitoring earthquake activity at UWA Farm Ridgefield

Project team: Vic Dent[1] (project leader: vic.dent@uwa.edu.au), Dr Ruth Murdie[2]

Collaborating organisations: [1]UWA; [2]Geological Survey of WA

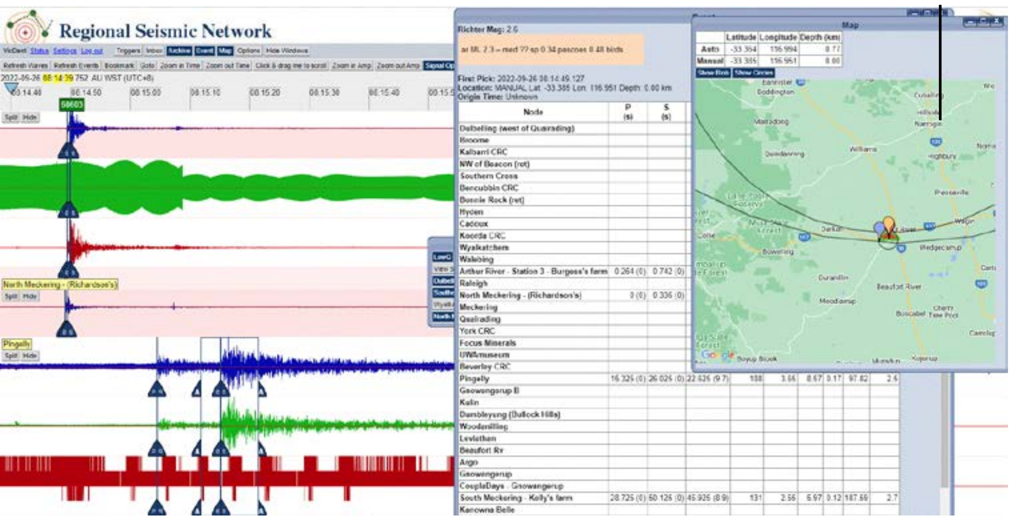
The WA wheatbelt was identified as a region of relatively high seismicity by Ian Everingham in 1966. Geoscience Australia (and its predecessors) began monitoring the region in 1957 and has been progressively adding new surveillance centres since then. My "PSN" network also has about 10 sensors in the wheatbelt, including one at UWA Farm Ridgefield (since 2015). This instrument has allowed locations for earthquakes in the wheatbelt to be made with more precision. It also allows us to more closely monitor two relatively active seismic centres nearby – i.e., about 30 km NE of Pingelly, and another centre west of Brookton.

The earthquake recorder at UWA Farm Ridgefield was restored to full functionality in 2022, after being out of action for nearly a year. It has since recorded many earthquakes from the WA wheatbelt area. Of particular interest were the events from the Arthur River area, one of which (magnitude 2.5) is shown in the figure. This area was the site of extreme activity in January and February of 2022, with more than 2000 earthquakes being recorded. Most were quite tiny (magnitude less than 1), but the largest was magnitude 4.8.

This activity could be rated as the most significant activity in WA for 20 years (when there was intense activity near Burakin, north of Dowerin). The recording the research team received has helped to identify a supposed fault line, from which the earthquakes occurred. Satellite measurements showed that the area about 5km southwest of Arthur River was raised by approximately 2cm by the earthquakes

This research is supported by UWA.

Plot of data for a magnitude 2.3 Arthur River earthquake on 26 September 2022 (08:14 hours, local time). Ridgefield (Pingelly) data is in the approximate centre of the plot.



UWA Aviation Labs team with prototype drone flown at the UWA Shenton Park Field Station.

UWA Aviation Laboratory: Low-cost open drone designs for agriculture

Project team: Dr Dilusha Silva[1] (project leader; dilusha.silva@uwa.edu.au), Dr Michal Zawierta[1], Dr Hemendra Kala[1], Dr Gurpreet Gill[1], Associate Professor Andrew Guzzomi[1], Jamir Khan[1], Robert Crew[1], Shami Mohdar[1], Brodie Dewar[1], Thehara Sumanarathna[1], Joo Kai Tai, Luvha Shrestra[1]

Collaborating organisation: [1]UWA

The rapid advancement of drone vehicles, both airborne and ground-based, holds immense potential for agriculture. While many drones are available for purchase, the cost of drones becomes large ($10,000 plus) when the payload size becomes large enough for practical agricultural applications. In addition, the drone operation tends to be tied to the systems provided by the manufacturer and tailoring to new applications becomes difficult. Agriculture could greatly benefit from swarm deployments of drones, and this will increase costs by at least an order of magnitude. For this reason, the UWA Aviation Lab has been established as a motivated group of staff and students who have come together to develop open drone designs that are low cost and flexible enough to be adapted to novel applications.

This team operates under the Engineering for Agriculture theme of the IOA, and the Microelectronics Research Group at the School of Engineering. During 2022, the UWAAL team has completed test flights of their initial prototype drone at the Shenton Field Station and begun work on a larger drone platform. In addition, new projects have been initiated on the development of communications and control hardware for drone swarms, and on understanding reliability in the drones used at UWA.

Vegetables on display at a local farmer's market.

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 2022. Our research focus contributes to the realisation of the 2030 Agenda of Sustainable Development.

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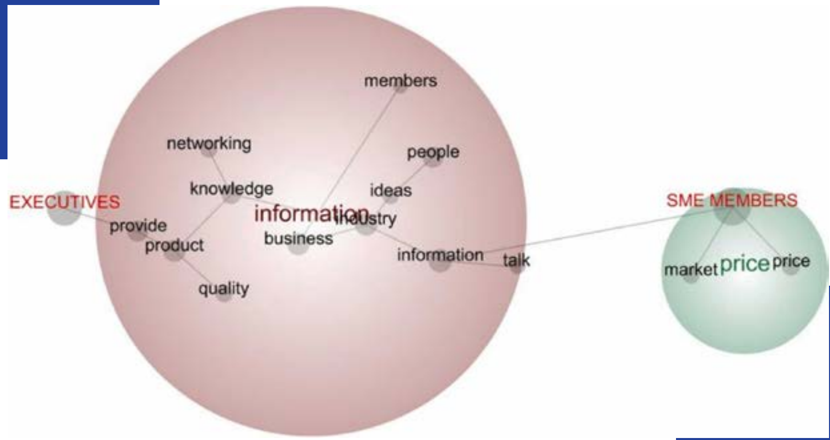


Leximancer analysis of executives and SME members.

Networking benefits for SME members of co-operatives

Project team: Dr Shahid Ghauri[2] (project leader; shahid.ghauri@curtin.edu.au), Winthrop Professor Tim Mazzarol[1], Winthrop Professor Geoffrey Soutar[1]

Collaborating organisations: [1]UWA; [2]Curtin University

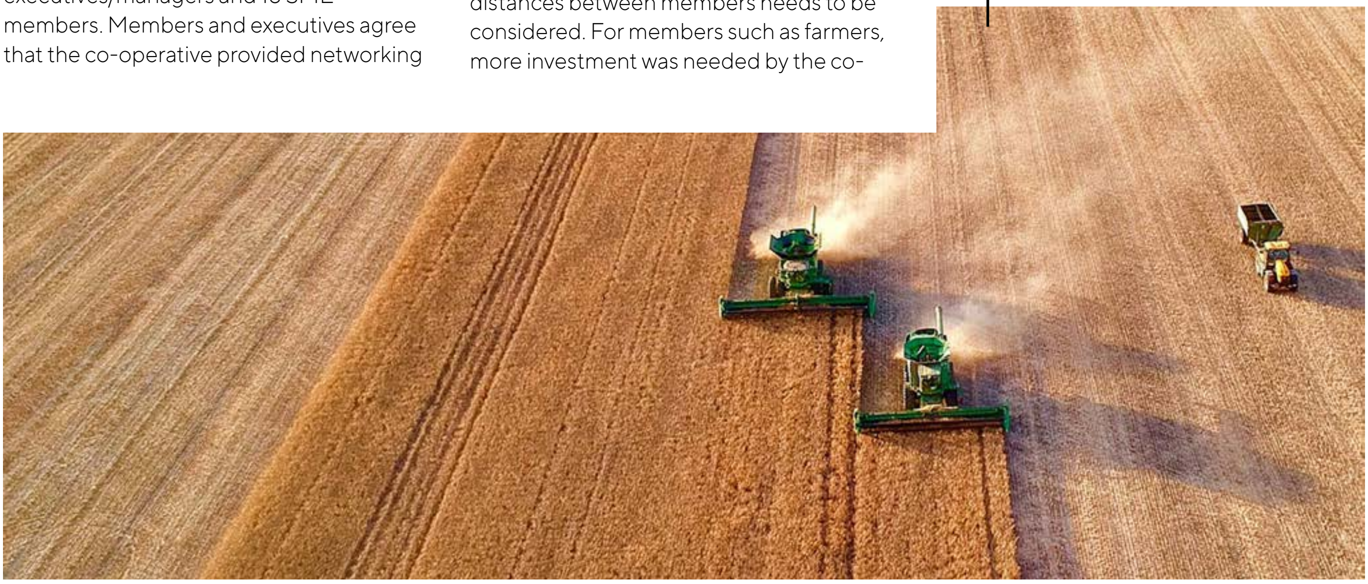
Co-operatives are seen as communities working collectively to achieve common goals. One of their main principles is that of being concerned about the communities in which they operate. They can leverage this to create more effective networking opportunities amongst their membership. This study explores how small and medium enterprises (SMEs) can benefit from networking by being members of a co-operative.

The research used a qualitative case study analysis of three co-operatives in Western Australia: CBH Group, Geraldton Fishermen's Cooperative, and Capricorn Society Limited. We interviewed nine executives/managers and 18 SME members. Members and executives agree that the co-operative provided networking opportunities for members to talk, share information and knowledge through the social/community events. SMEs members can see each other as communities towards a common objective rather than competitors. This enabled networking to be more purposeful in building long lasting relationships whilst simultaneously being collective owners of the co-operative. Co-operatives, apart from economic pursuits, can facilitate networking events to enable SME members to engage in communications with each other to enhance the power in the relationships realised through networking. In this manner social capital is developed.

A significant finding in this study is that co-operatives provide the social setting for SME members to talk and exchange information, however this must be done deliberately and taking the con-operatives context into account. For example, in this study it is realised that the geographically distances between members needs to be considered. For members such as farmers, more investment was needed by the co-operative to deliver a social networking platform. For other co-operatives such as Geraldton Fishermen's Cooperative and Capricorn Society Limited in this study, the proximity to other members created natural social networking scenarios. Investment into the networking did not require as much investment compared to CBH.

This research is supported by UWA and Curtin University.

CBH Group is a grain growers' cooperative that handles, markets and processes grain from the wheatbelt of Western Australia.



CASI technology demonstration in Rangpur, Bangladesh.

Understanding farm-household management decision making for increased productivity in the Eastern Gangetic Plains (Farmer Behaviour Insights Project)

Project team: Associate Professor 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], Mostafa Nurul Islam[8], Jon Marx Sarmiento[1]

Collaborating organisations: [1]UWA; [2]Agribiz RD&E Services; [3]University of New England (UNE); [4]Uttar Banga Krishi Viswavidyalaya; [5]Rajshahi University; [6]Nepal Agricultural Research Council; [7]Bihar Agricultural University; [8]RDRS-Bangladesh

The Understanding Farm-Household Management Decision Making for Increased Productivity in the Eastern Gangetic Plains Project, also known as the Farmer Behaviour Insights Project (FBIP), is a regional project led by the University of Western Australia commencing June 2018. The objective of the project is to understand the decision-making behaviour of South Asian farm-households on the adoption/adaptation of innovations and the critical factors that influence these decisions.

There are two sequential stages in this project:

1) Examining the value-add of behavioural economics (BE) in explaining adoption/adaptation decisions, and
2) Applying BE insights from Stage 1 in designing behavioural interventions and testing their effectiveness in 'nudging' farmers to adopt/adapt Conservation Agriculture-based Sustainable Intensification (CASI).

To date, the project has completed the focus group discussions, key informant interviews, baseline survey, value chain analysis of CASI machinery, six behavioural economics experiments, post-intervention survey, end-of-cropping season survey, and the endline survey. Currently, we are conducting the case study data collection. Results were disseminated through various forms including publication as journal articles (2), local and international conference presentations (30), reports (4), policy briefs (7) and several working papers.

The FBIP intervention helped streamline CASI service provision in the Eastern Gangetic Plains, particularly in West Bengal, where uptake of CASI technology is relatively high. An example of a successful BE intervention is the pre-commitment with micro-incentives which significantly increased CASI land allocation of farmers by an additional 0.82 bigha (0.13 ha) on average.

Other BE experiments tested include:

a) Nudging via text reminders,
b) Social proof to overcome inertia and increase CASI adoption,
c) Competition within groups to help improve seed replacement rate,
d) Field visit, protocol, and training reinforcements to overcome cognitive limitation biases, and
e) Framing video messages focussing on gender and herd behaviour to increase CASI adoption among men and women farmers.

This research is supported by UWA and ACIAR.

Nudging video shown in Gadhi, Nepal with local representatives.

Impact of COVID-19 on vegetable producers: The Case of Cauliflower and Broccoli Farmers in the Municipality of Aileu, Timor-Leste

Project team: Associate Professor Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Dr Vicente de Paulo Correia[2]

Collaborating organisations: [1]UWA; [2]National University of Timor Lorosa'e

The COVID-19 pandemic has affected vegetable farmers in Aileu, Timor-Leste, in producing and marketing their goods to the main markets in Dili. The Australian Centre International Agricultural Research (ACIAR) through its alumni research support facility funded a study led by National University of Timor Lorosa'e (UNTL) that examined how these farmers can better deal with issues caused by COVID-19 and offer potential solutions, recommendations and lessons learned. The research project partnered with UWA to provide guidance and support in conducting the project.

A farming family show off their broccoli harvest.

The study focused on cauliflower and broccoli producers. These men and women farmers supply their goods into the market through supermarket and mini markets, traders and collectors. Supplying directly to supermarkets is the most preferred channel for the producer. However, during the pandemic, this process faced new challenges in terms of limited quantity of the product needed, timing of delivery, prices and also the level of thrust. This trust-based relationship was tested during the pandemic, particular for producers, in terms of prices and quality product.

The pandemic caused a significant disruption in the production and marketing of the cauliflower and broccoli in Aileu including lack of supply of the product, delays in the distribution channels, low demand and low prices. All of these resulted from the lack of access to transport, lack of access to market and lack of movement of people and transportation.

The research team presented the preliminary results of the study to a wide range of stakeholders in a seminar in Aileu on 25 February 2022. In addition to communicating the research results, another objective of this well attended seminar was to get more feedback in relation to the impact of COVID-19. The seminar hosted Dean of UNTL's Faculty of Agriculture, Director of Ministry of Agriculture and Fisheries (Aileu), Administrator of the Municipality of Aileu Vila, and more than 50 participants. The participants included lead farmers, farmers' representatives, NGO staff, extension workers, Ministry of Agriculture and Fisheries (Dili, Timor-Leste) and other government department staff, heads of villages, traders, collectors and UNTL research students.

The study found that most producers experienced financial insecurity during the COVID-19 State of Emergency and lockdown in Timor-Leste. The main impacts were related to economic losses due to difficulties in marketing the products to the main market, but also difficulties in managing production systems through reduced access to inputs, such as seeds. Even with the restriction imposed on the community to reduce the spread of COVID-19, it didn't deter the farmers to continue producing cauliflower and broccoli and finding markets, but it did lower the quality of the products.

This research is supported by UWA and ACIAR.

Brocolli and cauliflower farm in the municipality of Aileu, Timor-Leste.

Overseas and return migration: Their determinants and impacts on smallholder farm households in Nepal

Project team: Dinesh Babu Thapa Magar[1] (project leader; dinesh.thapamagar@research.uwa.edu.au), Associate Professor Fay Rola-Rubzen[1], Associate Professor Ram Pandit[1]

Collaborating organisation: [1]UWA

A large-scale temporary labour migration primarily to Malaysia and the Gulf countries is rapidly transforming the agrarian economy of Nepal to a remittance-based economy in recent decades. Additionally, the country is also witnessing an increasing return of labour migrants from various overseas destinations. Therefore, this study using survey data collected from 665 farm households of Chitwan (terai/plain region) and Kaski district (hill region) of Nepal examined the determinants of overseas labour migration and migration intensity in the farming households, including factors influencing migrants' destination choice, return, occupational choice after return, and impacts of both overseas labour migration and return migration on the household economy, particularly on household welfare, investment and agricultural outcomes.

The study revealed a higher likelihood and a higher intensity of overseas labour migration in households with a higher proportion of educated members, access to credit, indebtedness, higher connection with migration networks and the opposite effect in households with heads having more farming experience, domestically employed household members, larger farm size, access to irrigation and a higher asset index. Additionally, the study revealed a lower likelihood of selection of Malaysia and the Middle East countries as migration destination by individuals with higher education, domestically employed members in the household, and asset index or wealth status. Those migrants that are married, head of the household, work in destinations such as Malaysia and the Middle East countries, have larger farm size and productive investments at home were more likely to return. Migrants' entrepreneurship after return was significantly and positively affected by migrants' education, accumulated income, and acquired skills overseas.

Overseas labour migration had significant positive contribution on improved household welfare of labour migrant households through increased per capita household income and per capita expenditure on food and non-food items. Return migration also contributed to improved welfare of returnee migrant households through increased per capita food and per capita total expenditure. Overseas labour migration also significantly contributed to a higher investment in physical capital such as in residential plots or non-farming land and in construction or renovation of houses. In contrast, return migration significantly contributed to both physical capital and productive capital investment such as in farm capital and non-farm businesses. Moreover, overseas labour migration appeared to negatively affect agricultural production (e.g., less cropped area and number of livestock raised) and crop management expenditure, whereas return migration had an insignificant effect on agricultural outcomes.

While the study findings indicate a vital role of information and services (or migration networks), credit access and human capital on attaining overseas labour migration by individuals/farm households; improved irrigation services, including agricultural extension and related support, and promotion of the sectors that generate income and employment opportunities appear to be crucial to curb overseas labour migration from farming households in Nepal. Additionally, formulation of strategies that assure employment and entrepreneurship prospects of unskilled and less educated migrant workers including the creation of environment for productive investment of migrants appear to be crucial for facilitating migrants' return and their productive reintegration after return. Human capital development as well as identification and promotion of options that encourage participation and investment of overseas labour migrant and returnee migrant households in both farm and non-farm productive sectors are other important areas needing emphasis of the government and stakeholders to accelerate the economy and maximise the development impacts of migration in Nepal.

This research is supported by UWA through the scholarship for International Research Fees, University Postgraduate Award, and Overseas Travel Award.

An example of fallow land in Nepal.

Increasing fallow land in Nepal with mountains in the distance.

A branch of cashew tree grown by smallholder farms in the Central Highland of Vietnam.

Analysis of the efficiency of smallholder farm perennial crop production in the upland areas of Vietnam

Project team: Le Van Cuong[1,2] (project leader; vancuong.le@research.uwa.edu.au), Associate Professor Atakelty Hailu[1], Associate Professor Michael Burton[1], Associate Professor Chunbo Ma[1]

Collaborating organisations: [1]UWA; [2]Vietnamese Academy of Forest Sciences

Upland areas take up two-thirds of Vietnam's territory and are diverse in biophysical and socio-economic conditions. Farming land is often fragmented, hilly, and relatively poor. Exported-oriented tree and crop production is a key feature of upland agriculture. In recent years, acknowledging the critical role of tree and crop production for rural livelihood and agriculture export earnings, the government has launched programs and policies to improve agricultural productivity. However, these governmental efforts have had limited success, suggesting a considerable gap between policies and farmers' preferences for production practices. Although there have been studies investigating the efficiency of coffee or tea enterprises in Vietnamese uplands, there has been little or no research on the efficiency of farms with multiple enterprises (tree and crop production).

This study investigates the degree of productive efficiency and its determinants using farm level data on both tree and crop production. It also examines farmers' preferences in relation to government policies designed to influence production practices of perennial crops. The study aims to promote higher efficiency and productivity in the upland areas by generating information that would help bridge the gap between government policies and smallholder farmer motivation.

This research is supported by UWA.

The tea plantations are harvested by smallholder tea growers in the northern upland of Vietnam.

Farm performance, laser land leveller adoption, and economic value of irrigation water in India: A directional distance function analysis

Project team: Sofina Maharjan[1], Associate Professor Atakelty Hailu[1] (project leader; atakelty.hailu@uwa.edu.au), Associate Professor Fay Rola-Rubzen[1], Dr Ram Pandit[1], Dr Jeetendra Aryal[2]

Collaborating organisations: [1]UWA; [2]International Centre for Biosaline Agriculture, United Arab Emirates

Water shortage in agriculture has become a serious global issue affecting production and food security, as agriculture accounts for 70 per cent of water use globally. Water scarcity is expected to be further exacerbated by global warming, climate change, and population growth in the coming years. India is one of the world's largest consumers of freshwater (ground and surface water), with 91 per cent of freshwater extracted being used for food production. Water is likely to be a more important constraining factor than land for sustainable agriculture and food security in India in the future. Although the green revolution in India tripled production, agricultural productivity has stagnated since the 1990s. Additionally, environmental concerns have been growing due to inefficient input use. One way to tackle the stagnant productivity, adapt to climate change and overexploitation of water resources is to enhance technical efficiency and use water management practices.

This study examined the degree and source of technical inefficiency among farmers in Punjab, India, the productivity effects of Laser Land Leveller (LLL) use, and the shadow price of irrigation water. Using a directional distance function approach, we found evidence of substantial technical inefficiency in the production system and that land ownership has a significant positive effect on productive efficiency. LLL adoption did not appear to have a significant effect on productivity, and the estimated shadow price of water was found to be low. The results suggest that productive inefficiency can be minimised, farm economic performance improved, and groundwater resources conserved through an improved mix of policy measures, including secure land tenure arrangement on leased land, providing reliable electricity and energy price choices, and promoting water-saving technologies along with information and training on land and crop management practices under such practices.

This research is supported by UWA and ACIAR through the John Alwright Fellowship.

A tractor and laser guided land leveller being used on dry soil.

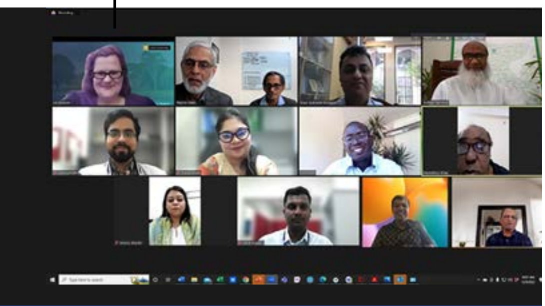
Assessing adoption and diffusion of agricultural innovations in Bangladesh

Project team: Professor Nazrul Islam[1,2] (project leader; nazrul.islam@outlook.com.au), Dr Gour Gobinda Goswami[3], Professor Zulfikar Rahman[3], Dr Amin Mugera[1], Hackett Professor Kadambot Siddique[1], Professor Mohamed Quaddus[2], Dr Elizabeth Jackson[4], Dr Fazlul Rabbanee[4]

Collaborating organisations: [1]UWA; [2]North South University; [3]Bangladesh Agricultural University; [4]Curtin University

Like many developing countries, the growth in agricultural productivity in Bangladesh is hampered by both low and slow adoption of available agricultural innovations.

A Zoom screenshot during a regular periodic project research team meeting in 2022.



To address this challenge, policy makers need to understand what are the available agricultural innovations and factors that hinder their adoption. The North South University in Bangladesh is collaborating the Bangladesh Agricultural University and international partners - Curtin University and UWA to address this challenge. In October 2021, the partnership received ৳20 million Bangladeshi taka (BDT) funding award from the Krishi Gobeshona Foundation (KGF), Ministry of Agriculture, Government of Bangladesh to implement the project.

The project aims to investigate the dominant innovations adopted by smallholder households across the country and key factors that determine both the decision to adopt, intensity of adoption and speed of adoption. The second aim is to investigate the attitudes and perceptions of the farmers towards agricultural innovations. Several activities were carried out in 2022 to achieve the aims of the project:

a) Expert consultation workshop held on 6 April 2022 at North South University, Dhaka to identify and choose significant agricultural technologies that the project would focus on.
b) In-depth Interviews with experts conducted from 12 June to 5 July 2022 in fifteen different locations to collect field data on the uptake and dissemination of technological innovations. Respondents were selected from both public and private sectors, including researchers from national agricultural research institutes, extension services, academia, media, international organisations, and farmer groups.
c) Focus group discussions conducted from 21 July to 8 August 2022 in five different locations to allow the research team to understand how adoption decisions vary across different agroecological zones.
d) Training on qualitative research method delivered by Dr Elizabeth Jackson, Senior lecturer at Curtin University, at NSU Australia visited NSU from 4th to 9th September 2022. The research assistants in the project learned how to use the NVIVO software to analyse qualitative data from in-depth interviews and focus group discussions.

This research is supported by the Krishi Gobeshona Foundation.

A Bangladeshi farmer carries his crop by hand in a canola field.

The importance of weather-year variation and tactics in whole-farm optimisation modelling

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

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

Farm management occurs against a backdrop of weather-year variation. How important is it for farming system models to capture this variation and the management tactics that are matched to that variation?

This project aims to:

a) Compare three farm optimisation model frameworks that vary in their representations of weather uncertainty, to identify the level of detail required for accurate farm modelling, and
b) Quantify the value of short-term tactical management in response to unfolding weather conditions.

Michael Young and AFO on the laptop out and about in the Great Southern among wheat crop.

Three different farm optimisation frameworks housed within Australian Farm Optimisation (AFO) that describe a farming system in Western Australia are compared and contrasted. The frameworks compared range from steady-state programming to multi-year stochastic programming with detailed representation of weather-year variation and associated farm management tactics. The frameworks are subject to various applications to test their differences and similarities.

Modelling results reveal significant differences in profit and optimal management outputs when representing weather-year variation and management tactics relevant to that variation. Inclusion of tactical decision-making increases expected profits by at least 14 per cent. These findings suggest that for accurate farm analysis, models must include weather uncertainty and relevant tactical management options.

This study paves the way by successfully demonstrating the application of multi-year discrete stochastic programming of mixed enterprise farm businesses in the Great Southern region of Western Australia. Furthermore, the study quantifies the value of applying farm management tactics in response to weather variation.

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

Rice fields in Northern Cambodia. In 2021, Cambodia was the seventh largest exporter of rice in the world.

Free Trade Agreements Foresight Study: Cambodia

Project team: Paul Baker[2] (project leader; baker@tradeeconomics.com), Loan Le[2], Dr David Vanzetti[1], Penghuy Ngov[2]

Collaborating organisations: [1]UWA; [2]International Economics Consulting Ltd (IEC); International Economics Consulting Ltd; ARISE Plus Cambodia; Government of Cambodia

As an agricultural exporter, Cambodia has always leveraged trade for fuelling economic growth, job creation, poverty reduction and government revenue generation. As a Least Developed Country, Cambodia has preferential access to several major markets. When it graduates from its LDC status in 2024, preferences will be reduced or removed entirely. Hence, Cambodia is seeking to expand market access through bilateral and multilateral free trade agreements (FTAs).

This study provides a comprehensive analytical foundation for identifying and prioritising potential free trade agreement (FTA) partners. The methodology involves computable general equilibrium analysis to identify the macro effects of bilateral FTAs, and partial equilibrium analysis of over 5000 tariff lines to identify which specific products have greatest potential. Major markets are likely to be the USA, the European Union and the United Kingdom. However, exporters to these markets face significant non-tariff measures, such as Sanitary and Phyto-Sanitary restrictions.

The project also has a capacity building aspect. It strengthens the analytical capacity for negotiations of FTA of Cambodia's trade policy stakeholders, and it will further equip government officials with sufficient understanding and skills to utilise the existing models and tools to evaluate the benefits and stakes involved in an anticipated trade deal.

This research is supported by the European Union and German Federal Ministry for Economic Cooperation and Development (BMZ). It was implemented by GIZ, ARISE Plus Cambodia and the Ministry of Commerce.

European honey bee (*Apis mellifera*) feeding on a flowering Broad-leaved Paperbark (*Melaleuca quinquenervia*).

European honey bee (*Apis mellifera*) feeding on a flowering Grevillea sp. Photos: Cheryl Day

Valuing Western Australia's natural resources for beekeepers

Project team: Associate Professor Ben White[1] (project leader; benedict.white@uwa.edu.au), Cheryl Day[1]

Collaborating organisations: [1]UWA; Department of Biodiversity, WA Conservation and Attractions; DPIRD; Western Honey Supplies Pty Ltd; Pemberton Honey Co.; Hive+Wellness Australia; Western Australia Apiarists' Society

Beekeeping is a well-established hobby and growing industry in Western Australia. Beekeeper hive numbers range from a single backyard hive in an urban environment; small-scale amateur operations with 40 hives or less; and large commercial beekeepers who migrate across the state managing hundreds of hives. Native flora is used for production of highly valued honey bee products. However, the industry faces environmental and management challenges resulting in lost productivity.

In addition to bush clearing which is a permanent loss of vegetation resources, bushfires (prescribed or otherwise) and logging impact honey production and render apiary sites unproductive for many years (up to decades). Variability of nectar flow and flowering physiology of some of Western Australia's most valued vegetation, in terms of production and quality of honey, such as Karri (*Eucalyptus diversicolor*), Marri (*Corymbia calophylla*) and Jarrah (*Eucalyptus marginata*) further complicates management of limited resources. Therefore, the industry's potential to exploit the growing domestic and overseas markets for "clean and green" honey is far below its potential.

In this project we aimed to estimate the value to beekeepers of the ecosystem service provided by Western Australia's endemic native vegetation and provide an estimate of hobbyist and small-scale amateur beekeepers' supply to the local honey market. For commercial beekeepers, a focus was to estimate the value of apiary sites and the productivity of migratory beekeepers. Through the design of a novel online quantitative survey, the Natural Resources for Beekeepers Questionnaire (Western Australia) 2020-21, this project has improved knowledge about the economics of beekeeping in Western Australia and provides information and data about productivity and behaviour of beekeepers which was previously lacking or out-of-date.

The questionnaire was the first comprehensive, spatially referenced survey of beekeepers in WA since 1990. It was also the first survey that measures the determinants of beekeeper profitability from honey production and pollination and was scaled to be equally applicable to a backyard beekeeper with a single hive and a commercial beekeeper running 1000 hives or more. Results enabled estimated supply from hobbyist and small-scale amateur beekeepers to the local honey market.

Our research found that backyard beekeepers gave away or consumed 87 per cent of the 66 t ($1 million) of honey they harvested in 2019 – 2020, while we estimated small-scale amateur beekeepers produced 109 t of honey worth $1.1 million to $1.8 million and distributed 56 per cent through private sales and wholesale processors (10 per cent). Commercial producers harvested over 2,700 t of honey worth approximately $27 – $56 million. The industry suffers a recurring annual loss of 30 per cent of revenue due to prescribed burning, as estimated by a 29-year simulation analysis. An adaptive burning policy that avoids burning when high value flowering events occur such as Jarrah (*Eucalyptus marginata*) flowering, is highly recommended.

The survey data helps to equip the industry with production data that can be factored into decisions related to apiary site management, prescribed burning and Forest Management Plans. The data is extensive and gives measures related to the production system and profitability of the WA beekeeping industry, focusing on the 2019 – 2020 season and historical production.

This research is supported by UWA and the CRC for Honey Bee Products.

Consumer behaviour: Technology tagging

Project team: Professor Sharon Purchase[1] (project leader; sharon.purchase@uwa.edu.au), Alua Devine[1]

Collaborating organisation: [1]UWA

This project aimed to examine the potential of Near Field Communication (NFC) and Quick Response (QR) tags for labelling and marketing honey products in overseas markets. These tags have the capacity to allow consumers to quickly and easily obtain links for batch tracing, educational information and marketing materials. This pilot study measured the initial consumer response to the presence of QR and NFC tags, specifically the proportion of tags used, the locations of users and the webpages visited by users.

NFC and QR code stickers were applied to the labels of honey products sent overseas and into local markets for sale. Each tag was designed to link consumers to a traced website created by the CRC for Honey Bee Products, enabling researchers to use Google Analytics to obtain demographic and behavioural data on any consumer who used the tags to access the website. From July 2021 to May 2022, researchers collected this data and analysed consumer behaviour within the website.

The NFC tag and the QR code were designed, printed and distributed to the four volunteer honey packers for placement on their honey jars prior to their sale.

The overall use of the tags was low, and this may be due to this research occurring during the COVID pandemic and the disruption to transport systems during this period. When considering the analyses of data on the use of QR and NFC codes attached to honey bottles and/or using such data to interpret outcomes, an analyst should be aware that there may be mitigating circumstances that have contributed to the use, or non-use, of QR and NFC codes by consumers. These mitigating circumstances might be, but may not be limited to:

a) The distribution of the honey containers into international ports,
b) The restocking of shelves or the non-restocking of shelves in stores that may have had excess inventory,
c) The time is taken to ship such inventory overseas or into Australian stores, and
d) The placement of new inventory behind lesser use by date inventory on shelves.

Unknown in this study was how many honey jars landed in each country and hence the bias of the numbers to Singapore and Japan, whilst technically advanced, may be due to Western Australian honey popularity in these markets. Indicative of this bias is the relatively high scanning activity in Australia, particularly Perth compared to other countries. The logistics of setting up this experiment highlighted that the NFC tags are a major expense and delayed the start of the experiment due the difficulty in their supply. QR codes on the other hand are easy to generate but also to copy. This project led our interaction with anticounterfeiting specialists and to the hosting of the anticounterfeiting workshop.

This research is supported by UWA and the CRC for Honey Bee Products.

Jars of the CRC for Honey Bee Products scientifically certified monofloral honey.

Chain of custody for honey products

Project team: Professor Sharon Purchase[1] (project leader; sharon.purchase@uwa.edu.au); Don Muir[2], Associate Professor Cornelia Locher[1], Khairul Islam[1], Dr Kate Hammer[1], Dr Liz Barbour[1]

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

The aim of this project was to consider the development of a system for assuring providence for Australian honey. Honey is one of the most adulterated food products globally and traceability systems will be an important tool for maintaining the quality reputation of Australian Honey. The first step in this process was the digitalisation of a quality assurance system BQUAL. In conjunction with this process another quality assurance system was developed for 'hobby' beekeepers: Btrace. B-Trace is a fully online quality assurance system for smaller/hobby beekeepers. These systems are now becoming important through the wider agribusiness industry for improved record keeping, benchmarking of industry standards and linking to other digitised systems that are being developed.

The next part of this project was the development of a system that can be used to assure providence. In conjunction with a range of UWA schools a system was developed that displayed the providence for mono-floral honey. Through the use of QR codes and development of a website, a prototype system was developed to highlight to honey packers how providence can be communicated to their consumers.

This research is supported by UWA and the CRC for Honey Bee Products.

The B-QUAL logo, with quality and hygiene guarantee.

The QR code on top of a jar of honey.

Label cues to influence honey purchases

Project team: Associate Professor Fang Liu[1] (project leader; fang.liu@uwa.edu.au), Kenneth Ho[1], Juanyi Sunny Liu[1], Lingyu Gao[2], Dr Liz Barbour[1]

Collaborating organisations: [1]UWA; [2]Tongji University, China; Bee Industry Council of Western Australia (BICWA); UAF Association; One Flower Honey; Hive+Wellness Australia Pty Ltd; Australian Natural Biotechnology Pty Ltd; WA Pure Honey; Mother Kangaroo Australia; Bee Firm NRG

A food label is essential for every food product, which provides salient product information (or cues) that facilitate consumers' evaluation of the products. However, the effectiveness of using food labels as consumer purchasing aids will largely depend on consumer attention. Due to limited cognitive capacity and time constraints, consumers are unable to process all cues or information on a food label. Understanding consumers' attention toward food label cues may become more complex when considering cross-national and cross-cultural differences in honey purchases. These issues have led to the development of multiple studies which has an overall aim to better understand the role of product label in consumers' attention and evaluations of Australian honey in international markets.

The main objectives of this project were to understand:

a) The influences of honey product labels on consumers' attention and evaluation of Australian honey products domestically and internationally,
b) The influences of honey product labels on pricing perceptions,
c) The influences of honey product labels on health consciousness, and
d) The co-marketing potential between honey and tourism.

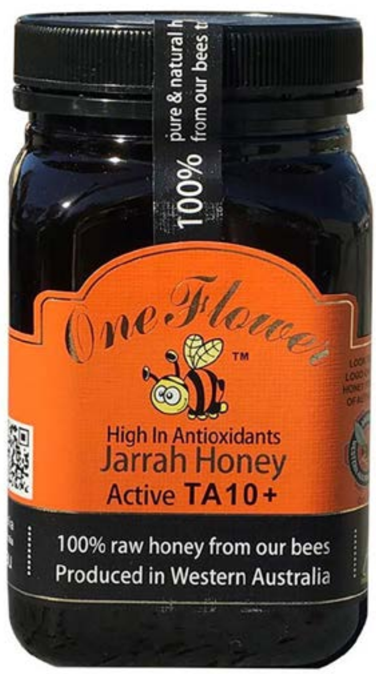
Results show that consumer attention to Australian honey labels is significantly influenced by the nature of the label cues. For example, attention to health-related and assurance-related cues are significantly different among Eastern and Western consumers. Furthermore, the cognitive processing of key label cues, such as pictorial brand logos and geographical cues, have also been found to influence consumers' evaluations of Australian honey products, such as product value perceptions, product authenticity, willingness to pay a premium price, and purchasing intention.

To effectively market Australian honey in international markets, Australian honey marketers and exporters should also pay attention to their pricing strategies in different countries. Prices can offer important information to consumers (e.g., product quality, authenticity, etc.) and can assist consumers to make informed purchasing decisions. However, consumers may be confused by the pricing information. This study finds that pricing confusion when evaluating Australian honey product labels is caused by various market factors, such as channel, knowledge, and involvement.

Prior research examining the relationship between product and place has focused on the influence of place on the product. Local products (i.e., honey) have received increasing attention in tourism marketing in recent years. Local products can assist tourists to form memorable tourism experiences, which may influence tourists' place loyalty and revisit intentions. Further, local products help a tourism destination establish a unique 'sense of place'. This project also investigated a potential comarketing alliance between honey products and tourism. Evidence suggests that consumers tend to favour Australian honey, which is strongly associated with a tourist place.

This research is supported by UWA and the CRC for Honey Bee Products.

CEO of the CRC for Honey Bee Products Dr Liz Barbour.



A 250ml container of One Flower Jarrah honey. This product label was among those used and modified for the study.

An Australian beekeeper extracting honey from a hive.

This image was used as the experimental marketing design for BICWA.

Developing the story for Western Australian honey

Project team: Professor Sharon Purchase[1] (project leader; sharon.purchase@uwa.edu.au), Dr Daniel Schepis[1], Dr Liudmila Tarabashkina[1], Dr Kim Feddema[1,2]

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

This research investigated the marketing strategies currently used within the Western Australian (WA) honey industry, how they align with labelling requirements and how these messages are received by consumers in six target international markets (India, Japan, Malaysia, Saudi Arabia, United Kingdom, and United States).

To accomplish this objective, we first conducted preliminary qualitative analyses of current marketing strategies and carried out in-depth interviews with honey industry stakeholders. Subsequently, we conducted preliminary qualitative focus groups with consumers from the six target countries, which informed a quantitative experimental study to test the effectiveness of different marketing narratives (Health, Production, Flavour, Terroir) and varying specificity of Product Origin (Region, State and Country level).

Experimental data showed that there are differences amongst consumers, both for honey products and for marketing narratives. This report concludes with marketing strategy recommendations for honey producers and packers wishing to export their products into these six target markets and the price premium that exporters may be able to achieve.

Results were disseminated back to industry through events such as the BICWA monthly breakfast, a four-hour UWA workshop focused on strategies for export attended by members of DPIRD and BICWA, and ongoing informal discussions.

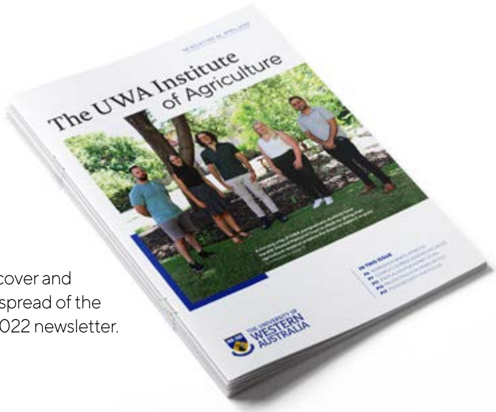
This research is supported by UWA and the CRC for Honey Bee Products.

An aerial photo of Winthrop Hall at The University of Western Australia's Crawley campus.

7

Education and Outreach Activities

Strengthening communication links with industry, farmer groups and the broader regional and international scientific communities is one of IOA's key strategies. A number of 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 2022 newsletter.

Newsletters

The 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, and December, the newsletter is circulated widely in electronic format and hardcopy to more than 5000 readers. Ten newsletter stories were republished as articles in newspapers *Farm Weekly* and the *Countryman* in 2022.

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 2022, IOA's social media audience increased significantly. The IOA LinkedIn grew by 1981 new followers to a total of 2,890, and event videos published to YouTube in 2022 amassed 3,495 views. More than 250 people subscribed to the YouTube channel in 2022. The @IOA_UWA Twitter exceeded its growth rate from the previous 12 months, ending the year with approximately 2,706 followers.

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 2022, IOA hosted more than 45 individuals from local, national and international organisations at the Crawley campus.

In February, leading WA researchers served up a smorgasbord of thought-provoking presentations at IOA's workshop on Food Quality and Human Health.

The event was held in the UWA EZONE and organised by the IOA's research theme leaders Professor Trevor Mori from the UWA Medical School (Royal Perth Hospital Unit) and School of Molecular Sciences Associate Professor Michael Considine.

In April, the IOA hosted Federal Agriculture Minister the Hon David Littleproud MP for a special event to announce a $4.34 million grant to UWA as part of the national Soil Science Challenge.

The long-time partnership between UWA and the Academy of Scientific and Innovative Research (AcSIR) was further fortified when AcSIR visited IOA in August.

IOA Director Hackett Professor Kadambot Siddique and AcSIR Director Professor Rajender Singh Sangwan made history earlier in 2022 when they launched the first-ever joint PhD program between UWA and an Indian research institution.

Professor Sangwan and his team travelled to Perth from Uttar Pradesh to finalise details of the new joint PhD program.

In October, the Australian Ambassador to Iraq Paula Ganly paid a special visit to IOA.

Ms Ganly and Professor Siddique discussed UWA's engagement and collaboration with the Higher Committee for Education Development in Iraq since 2005.

Also in October, leaders from Acharya N.G. Ranga Agricultural University (ANGRAU) connected with joint UWA-ANGRAU PhD students at a special meeting at UWA hosted by IOA.

The Government of Andhra Pradesh's Minister for Agriculture, the Hon Sri Kakani Govardhan Reddy, and Consulate-General of India (WA) Consul Naresh Sharma attended alongside ANGRAU Vice Chancellor Dr A Vishnuvardhan Reddy, Registrar Dr G Rama Rao, Agricultural Extension Professor Dr K Gurava Reddy and Agricultural Engineering College Associate Dean Dr A Mani.

UWA Deputy Vice Chancellor (Research) Professor Anna Nowak joined Hackett Professor Kadambot Siddique and fellow UWA staff and academics at the meeting.

Bean Breeding Global Lead Dr Clare Mukankusi and bean breeder Winnyfred Amongi, from the Alliance of Bioversity and CIAT (International Center for Tropical Agriculture) visited UWA in October.

The Australian Centre for International Agricultural Research (ACIAR) supported their visit to Australia for two weeks of training in genetics and breeding.

In November, IOA took a group of delegates from the University of Mataram (UNRAM) in Indonesia on a tour of the UWA glasshouses.

The visitors included UNRAM Rector Professor Bambang Hari Kusumo, Vice Rector for Planning, Collaboration and Information System Dr Yusron Saadi, numerous esteemed heads of departments and faculties (such as Dean of the Faculty of Agriculture Dr Sudirman) professors and members of UNRAM senate.

Photos (clockwise from left):

Presenters and guests at the Food Quality and Human Health workshop in February.

Professor Sangwan and his team with UWA academics and heads of schools.

Professor Wallace Cowling, Dr Clare Mukankusi, Winnyfred Amongi, Dr Renu Saradadevi and Hackett Professor Kadambot Siddique.

Emerita Professor Lynette Abbott, Hackett Professor Kadambot Siddique, Federal Agriculture Minister the Hon David Littleproud MP, UWA Vice Chancellor Professor Amit Chakma and UWA Deputy Vice-Chancellor (Research) Professor Anna Nowak.

Hackett Professor Kadambot Siddique with Australian Ambassador to Iraq Paula Ganly.

Leaders from Acharya N.G. Ranga Agricultural University and UWA, PhD students and esteemed guests outside UWA's Winthrop Hall.

Below: PhD candidate Mohammad Salim presenting his research to UNRAM delegates.

Emeritus Professor Graeme Martin, Hackett Professor Kadambot Siddique, Dr Kelsey Pool, Philip Gardiner and Emeritus Professor David Lindsay.

UWA Lefroy Fellow 2022 Research Seminar

After decades of believing that ovine clover disease was purely a ewe-oriented issue, the new discovery that rams are also affected was revealed at the UWA Lefroy Fellow 2022 Research Seminar in May.

Lefroy Fellow Dr Kelsey Pool told the audience that her research team had demonstrated, for the very first time, that phytoestrogens alter ram reproductive function and provide evidence of a mechanism for this event.

"Our research shows that the phytoestrogens (plant-based compounds that mimic the hormone estrogen) associated with clover disease detrimentally impact sperm function in-vitro, reducing fertilising potential," Dr Pool said.

"In rams grazing oestrogenic pasture, reproduction was also reduced, however this effect is transient and does not persist to the following breeding season."

The E.H.B Lefroy Research Fellowship was established through a bequest by Sir Edward H.B. Lefroy and his family for post-doctoral candidates to undertake agricultural research at UWA.

The IOA seminar was focused on research outcomes from the past 18 months of the Fellowship, including results from on-farm trials, multi-generational fly models and lab work across several institutes in WA.

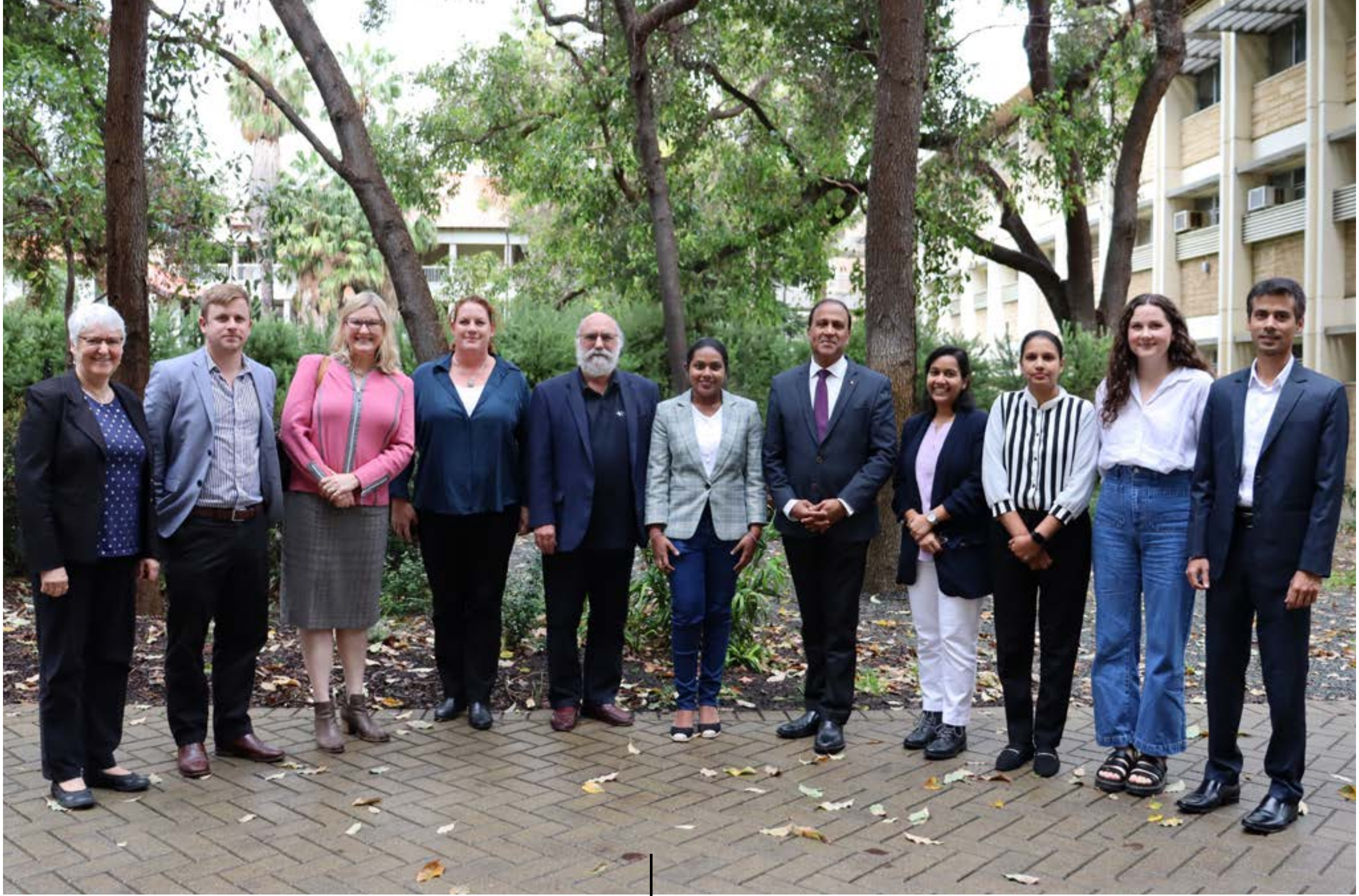
Dr Pool also presented her research findings on how commercially available neurohormone (slow-release melatonin tablets) can impact twin-lamb survival.

Following the research trial, Dr Pool found that lambs exposed to melatonin in utero had increased weight and brown fat, marking and weaning percentages, weight gain, learning ability, vocalisation, and behaved more inquisitive or bolder.

"The main take away from the research was that melatonin was having a physiological response," she said.

"The events that happen in utero or early life drive production outcomes and how they (lambs) navigate life into future years."

Dr Kelsey Pool delivering the Lefroy Fellow 2022 Research Seminar.



Emerita Professor Lynette Abbott, Professor Anna Nowak, Emeritus Professor Graeme Martin and Hackett Professor Kadambot Siddique with the student presenters.

Postgraduate Showcase: Frontiers in Agriculture

The importance of early-career researchers at UWA was the focal point of Deputy Vice-Chancellor (Research) Professor Anna Nowak's stirring address at the IOA's 2022 Postgraduate Showcase in June.

"There are many ways of measuring success...when we consider our highly cited authors and research funding success, many of our celebrated academics have roots in the Institute," Professor Nowak told the 80-strong audience.

"We can also look at the many PhD students ... being immersed in an environment of excellence and with opportunities like today to discuss and present their work with leading researchers."

Under the mentorship of Emeritus Professor Graeme Martin, six of UWA's best and brightest postgraduate students in agriculture and related areas presented their research at the 16th annual event.

First session chair CSIRO scientist and the IOA's Industry Advisory Board member Dr Hayley Norman introduced Md Khairul Islam from the School of Allied Health.

Mr Islam's project, funded by the CRC for Honey Bee Products, explored the use of High-Performance Thin-Layer Chromatography as a novel approach for analysing different varieties of WA honeys.

The UWA School of Agriculture and Environment (SAgE) PhD candidate Tanushree Halder then discussed her research aim to unravel the genetics of wheat root system architecture.

UWA Deputy Vice-Chancellor (Research) Professor Anna Nowak.

Third speaker Joe Gebbels from SAgE, who also works as a program manager at Meat & Livestock Australia, expanded on his recent findings that improving productivity reduces methane intensity but increases the net emissions of sheep meat and wool enterprises.

Following the afternoon tea break, second session chair UWA Emerita Professor Lynette Abbott introduced Sajeevee Sarathchandra from SAgE.

Soil scientist Ms Sarathchandra presented her research on remediating iron ore mine tailings by growing perennial ryegrass with organic amendments.

Having recently submitted her PhD thesis, Bhagya Dissanayake from the ARC Centre of Excellence in Plant Energy Biology and School of Molecular Sciences was pleased to discuss her success in uncovering the hidden adaptations of bread wheat roots under salinity stress.

The final speaker of the afternoon was Isobel Sewell from the School of Biological Sciences and UWA Ocean Institute, whose project at the Shenton Park Field Station investigated the use of black soldier fly protein in freshwater aquaculture diets.

Industry Forum

Navigating the Global Agricultural Marketplace in the Indian Ocean Rim: Spotlight on India and Indonesia

Taking place just a few weeks after newly elected Australian Prime Minister Anthony Albanese emphasised that India and Indonesia offered "enormous economic opportunities", IOA's 2022 Industry Forum had its finger firmly on the pulse of geopolitics and trade.

Farmers, industry members and academics gathered at The University Club of WA on 19 July for the 16th annual event to explore the theme 'Navigating the Global Agricultural Marketplace in the Indian Ocean Rim: Spotlight on India and Indonesia'.

In his opening address, Deputy Leader of the Opposition the Hon Colin de Grussa MLC aid the topic could not have been more timely.

"Given the numerous developments happening with our near neighbours, it is very appropriate we have this discussion today," Mr de Grussa said.

UWA Professor Stephen Smith, who chairs the UWA Public Policy Institute Advisory Board and sits on the board of the Perth USAsia Centre, captivated the audience with his keynote presentation.

Professor Smith expertly set the scene by explaining the current geopolitical climate, where Australia was positioned strategically, and how that can work in the best interests of the State and national agricultural industry.

"The single most important thing that Australia can do – in terms of its place in the world, its security and prosperity – is to grow our economic trade, investment and economic relationship with these countries to a much higher level," he said.

Delivering his presentation from India via video, technology strategist Deepak Pareek explored how India was unlocking its potential in agriculture to become the food capital of the world.

Drawing on his experience as chief executive of agriculture market intelligence firm AgriWatch, Mr Deepak emphasised digital and technological advancements that would improve India's agricultural market potential.

WA grain grower Jules Alvaro, the director of a broadacre business in Nokaning who sits on the Muresk Institute Advisory Committee, used her lived experience and on-farm photography to demonstrate her unique perspective on the topic.

> "I have tried to shine a spotlight on these countries since I first became Foreign Minister back in 2007."
>
> **Professor Stephen Smith**

Austrade Senior Trade and Investment Commissioner Sally Deane presented via video from Jakarta to explain what WA farmers and industry could be doing to enhance the current state of Australia's trade relationship with Indonesia.

The final speaker of the afternoon was Arthur River and Kalgan farmer Brad Wooldridge, who promised a "controversial ride" in discussing the pressures growers were under to balance productive output with increased restrictions and roadblocks.

ABC national regional affairs reporter Eliza Borrello then took to the stage to facilitate a rousing panel discussion, after which attendees gathered for a well-earned networking sundowner.

Presenters Brad Wooldridge, Hackett Professor Kadambot Siddique, Jules Alvaro, the Hon Colin de Grussa MLC, Eliza Borrello and Professor Stephen Smith at the 2022 Industry Forum.

Symposium attendees on stage at the University Club of WA main auditorium.

Celebrating the Career & Contributions of Emeritus Professor Graeme Martin

When he looked out over the sea of faces gathered to celebrate his five-decade milestone of teaching and research at UWA, Emeritus Professor Graeme Martin admits to feeling a little overwhelmed.

IOA and the SAgE jointly held a special symposium in July to mark Professor Martin's significant career and contributions at the university.

"I went into this event with a mix of warmth and trepidation," he said.

"Warmth because of the effort being made on my behalf by people I cherish ... trepidation because I do not like to be the centre of attention."

The welcome address was delivered by UWA Deputy Vice-Chancellor (Research) Professor Anna Nowak, during which she fondly recalled her first email interaction with Professor Martin that he ended: "Best wishes, cynical old man".

"I believe you should change your email signature from 'cynical' to 'wise'," Professor Nowak said.

"If wisdom is the ability to contemplate and act using knowledge, experience, understanding, common sense and insight – I think that would be a much more fitting sign-off."

Kicking off the event was Dr David Masters, who traced Professor Martin's roots growing up on a sheep and cereal farm to his many decades teaching and researching reproduction, livestock, and agricultural sciences at UWA.

Professor Alan McNeilly joined the event via live video from Scotland to speak about Professor Martin's post doctorate adventures in Europe.

> "Together, they had a lot of dirt on me but, thankfully, there were not too many embarrassing stories."
>
> **Emeritus Professor Graeme Martin**

Professor Steve Walkden-Brown, Dr Maria Hötzel, Associate Professor Dominique Blache and Associate Professor David Miller then covered the many aspects of his research into sheep reproduction in the 1990s.

Following Dr Penny Hawken and Dr Trina Jorre de St Jorre, who talked about 'Social sheep', Dr Irek Malecki and Dr Judy van Cleeff explored Professor Martin's emu research achievements.

Sheep Worm Team members, Dr Johan Greeff, Dr Shimin Liu and Shamshad Ul Hassan, then spoke on worms, flies, and the immune system.

Professor Martin said he was surprised by the sheer number of people who attended the event, which was overwhelming when he stood on-stage to present his right of reply.

"As the symposium progressed, with warm messages from people I cherish as colleagues and friends, I reflected over my 50 years at UWA and came to the realisation that my most important contribution was to the personal development of postgraduate students," he said.

"This became crystal clear when international students Shoaib Khan and Suyog Subedi spoke, right at the end of the program.

"Their heartfelt words brought tears to my eyes and made me reflect on the 40 or so little pockets of positive influence that I have scattered around the world. It was very humbling."

Professor Martin said he was very thankful to his most cherished friends and colleagues from over the decades who helped organise the event.

Shenton Park Field Station 2022 Open Day

In September, the UWA Shenton Park Field Station threw open its gates to the public for its first community open day in almost 10 years.

The formalities began with IOA Director Hackett Professor Kadambot Siddique welcoming attendees to the site, which has served the science and agriculture industries of WA for more than 60 years.

UWA Vice Chancellor Professor Amit Chakma took to the stage to introduce Parliamentary Secretary to Food and Agriculture Minister Alannah MacTiernan, the Hon Darren West MLC, to formally open the event.

Head of SAgE Associate Professor James Fogarty then outlined the eight research projects on show – ranging from aquaculture to breeding canola for heat tolerance.

Students and locals alike made a beeline for the Future Green Solutions stall to get up close and personal with black soldier fly larvae.

The FGS team explained how they uses the critters to upcycle low-value organic waste into high-value products.

Just next door at the UWA Aquaculture Facility, UWA Oceans Institute and School of Biological Sciences PhD candidate Isobel Sewell delivered a presentation on how she was using BSF larvae in aquaculture diets.

Aspiring coastal engineers were keen to tour the 1900 m^2 multipurpose hydraulics laboratory space, which can simulate offshore environments ranging from the deep ocean to shallow water.

The Coastal and Offshore Engineering Laboratory is used for a wide range of research, from testing performance of deep-sea vehicles to assessing stability of underwater cables.

During the Open Day, they demonstrated recent model testing techniques used for coastal and offshore engineering applications.

The event was one of the first opportunities for the public to visit IOA research theme leader Associate Professor Andrew Guzzomi's new Centre for Engineering Innovation: Agriculture & Ecological Restoration.

Out in the field plots, UWA Associate Professor Phillip Nichols presented on the Annual Legume Breeding Australia (ALBA) project with Senior Research Officer Brad Wintle.

Nearby, Australian Herbicide Resistance Initiative research fellow Dr Roberto Busi presented on herbicide resistance in ryegrass.

In the shadehouses, research fellow Dr Sheng Chen and Professor Wallace Cowling presented on their canola research projects – a GRDC-funded heat tolerance trial and NPZ-UWA canola breeding partnership, respectively.

Information stalls run by Animal Care Services and the UWA School of Agriculture and Environment were kept busy answering questions about research and study at UWA, while the Students of Natural and Agricultural Sciences fundraiser sausage sizzle ensured no-one went hungry.

The hugely successful event, which was jointly organised and run by IOA and SAgE, would not have been possible without the hard work and dedication of dozens of staff members and volunteers.

The hugely successful event, which was jointly organised and run by IOA and SAgE, would not have been possible without the hard work and dedication of dozens of staff members and volunteers.

Photos (clockwise from left):

Associate Professor James Fogarty, UWA VC Professor Amit Chakma, Hackett Professor Kadambot Siddique and Forrest Research Foundation Director Professor James Arvanitakis.

PhD candidate Isobel Sewell.

The Hon Darren West MLC at the Coastal and Offshore Engineering Laboratory.

Associate Professor Wallace Cowling.

Postgraduate student volunteers.

A group gathers for Dr Roberto Busi's presentation.

Ian McClelland delivering the 2022 Hector and Andrew Stewart Memorial Lecture.

Hector and Andrew Stewart Memorial Lecture

With one of the biggest harvests in WA history on the horizon, Ian McClelland shared his increasingly optimistic outlook at the 2022 Hector and Andrew Stewart Memorial Lecture in October.

A packed lecture theatre of almost 100 people turned up to hear the Birchip Cropping Group (BCG) founder deliver the 28th lecture for IOA.

Mr McClelland, who was the 2004 recipient of the GRDC Seed of Light Award, travelled from his 8300ha mixed cropping farm in Birchip, Victoria to share his insights.

His lecture traced the history of farming in Australia and WA, celebrated its current boom times, and looked forward to the future.

Set to a scrolling backdrop of BCG photos taken over the past 30 years, Mr McClelland reminisced about a time when many financial counsellors wouldn't invest in agriculture.

"Now, we suddenly have investments by superannuation funds and big corporations," he said.

Mr McClelland said farmers had always benefitted from science and technology – now more than ever.

"We have many new crops to plant, an advanced understanding of farming systems research, and can now make informed on-farm decisions based on history, data, weather forecasts and individual expertise," he said.

"Even so, the future poses many challenges, including the impact of climate change, and significant gap between potential and actual yields based on water-use efficiency."

Mr McClelland said WA would continue to see good results on the condition that farmers continued to educate themselves and be innovative.

He mentioned that BCG spent about 30 per cent of their income on farmer extension and education regarding more efficient farming practices.

"I think today's farmer is much more switched on in relation to the science that is making agriculture a boom industry," he said.

The IOA holds this lecture in honour of the late Hon Hector J Stewart, MLC and his son, the late Andrew M Stewart.

Mr Stewart Jr was President of UWA's Guild of Undergraduates in 1929 and twice Dean of UWA's Faculty of Agriculture.

Following the lecture, the Stewart family and friends gathered for a sundowner with UWA leaders and special guests in the Science Common Room.

Ian McClelland presenting at the lectern.

Professor of Natural Resources Meththika Vithanage delivering her lecture.

Microplastics in the Environment

Given the majority of microplastics research is focused on marine and freshwater abundance, Professor Meththika Vithanage is urging scientists to turn their attention to investigating microplastics in soil and air.

The IOA Adjunct Professor made this call to arms during her October lecture at UWA titled 'Microplastics in the Environment: Challenges and opportunities in environmental research'.

Professor Vithanage is the founding Director of the Ecosphere Resilience Research Centre, University of Sri Jayewardenepura, Sri Lanka and an Adjunct Professor at the University of Petroleum and Energy Studies, India.

She said microplastics in the size range from 100 um to 5 mm are ubiquitous in the environmental triad: soil, water, and air.

"Application of plastic mulch film, compost and biosolids into agricultural soils induce a threat to soil physico-chemical and biological properties," she said.

"Microplastics in the water environment may also act as a vector transporting various pollutants from one place to another."

Microplastics and plastic additives such as plasticisers may end up in the food web, bioaccumulate and cause health risks.

However, Professor Vithanage said there were limited studies on the effect of microplastics in soil and air.

"Most of the literature focus on reporting the abundance, and hence there are ample opportunities for multidisciplinary and collaborative research related to microplastic and environmental health," she said.

During her week-long visit, Professor Vithanage met with several UWA researchers and discussed potential areas of collaboration.

UWA Professor Ross Kingwell presenting in front of a green screen at the first virtual Grains Research Update. Photo: GRDC

GRDC Grains Research Update

Filming in a green screen studio, live streams and virtual Q&As were among the inventive ways the Grains Research and Development Corporation captured audiences' attention at the 2022 all-virtual annual forum.

Due to COVID-19 restrictions and safety concerns, the 2022 GRDC Grains Research Update Perth was held online over six days in February and March.

On 22 February, Australian Herbicide Resistance Initiative research agronomist Dr Mike Ashworth presented on 'The interaction between wheat establishment timing and pre-emergent herbicides choice on annual ryegrass seed production'.

Later that day, UWA School of Agriculture and Environment Dr Elizabeth Peterson joined a panel discussion to explore the topic 'Fertiliser strategies in response to higher prices'.

New researcher snapshots were delivered by SAgE scientists Drs Caitlin Moore and Hira Shaukat on 'The power of flux towers for measuring crop productivity and water use' and 'Soil moisture mapping in agricultural fields using electrical conductivity sensing', respectively.

On the fourth day Dr Roberto Busi gave a 2021 herbicide resistance update from AHRI, outlining the most significant results from the field to the lab, followed by Dr Fiona Dempster's talk titled 'Yes, no, maybe – getting value from herbicide resistance testing. SAgE PhD candidate and DPIRD researcher Miranda Slaven provided a new researcher snapshot on electric weed control in Australia.

Final presentations came from IOA research fellow Dr Sheng Chen on his research into canola pre-breeding for heat tolerance, and UWA Professor Ross Kingwell from the Australian Export Grains Innovation Centre on 'Growing a future for oats'.

Best Practice Farming Systems (BPFS) Project: 2022 Highlights

UWA PhD candidate Callum Connolly and Master's student Rida Malik at the Old Wool Shed.

To unlock the full potential of research at UWA Farm Ridgefield, the Best Practice Farming Systems (BPFS) Project was established in January 2022. The UWA Institute of Agriculture held workshop to reflect on what the Future Farm 2050 Project had achieved since its inception in 2009, and to consider what improvements could be made for the future. The workshop identified several critical issues that were holding back the FF2050 Project.

Required changes included better integration with UWA Farm Ridgefield, prioritisation of research and innovation, greater clarity of purpose, appropriate infrastructure and stronger governance and accountability frameworks. In response to these findings, the IOA launched the BPFS Project in January 2022 – marked by the publication of the *BPFS Project Strategic Plan 2022-2027.*

The BPFS Project vision is best practice solutions for resilient farming systems, environmental stewardship and community engagement. It marks a new chapter for innovative research at UWA Farm Ridgefield. According to the Strategic Plan 2022-2027, the BPFS Project will develop and support five Strategic Priorities that will require cross-disciplinary approaches. These will focus on sustainable production systems, managing biodiversity and ecosystems, and communication and translation of our research and innovation and education offerings for societal benefit.

Outreach

The BPFS Project is part of the Merino Lifetime Productivity (MLP) Project, The 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, and the TERN Critical Zone Observatory.

The BPFS Project's strong online presence enabled engagement with people all around the world. A total of 2,547 people were following the BPFS Project page on Facebook by the end of 2022. Throughout the year, 11 newsletter stories, three media articles and five peer-reviewed research papers were published. Results from the National Variety Trial (NVT) lupins grown at Ridgefield were circulated by GRDC in 2022. *The Economist* also published an article featuring Ridgefield on how gut bacteria may help combat nematode infestations in sheep.

The Massive Open Online Course Discover Best Practice Farming for a Sustainable 2050 attracted a further 5,000 enrolments in 2022, reaching a total of more than 36,000 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 Kelsey Pool delivered the Lefroy Fellow 2022 Research Seminar at UWA Bayliss Lecture Theatre in May. She explored her research achievements based at UWA Farm Ridgefield to UWA staff and students, industry and community members.

Dr Pool was also among the UWA scientists who participated in The WA Livestock Research Council (WALRC) Study Tour in June. Approximately 70 producers, consultants and researchers attended the event at UWA Farm Ridgefield to learn first-hand about livestock research and hear presentations covering a wide range of research topics relevant to the lambing industry. Presentations were made by, Professor Shane Maloney, Dr Pool, and UWA students Luoyang Ding, Georgia Welsh and Eloise Boland.

In June, a field day for agricultural consultant Farmanco was held, hosted by Murdoch University and facilitated by Farm Manager Tim Watts, to discuss the findings from the Merino Lifetime Productivity (MLP) Project.

At the Dowerin Field Days from August 24 to 25, the IOA's information stall featured posters and flyers on UWA Farm Ridgefield and the BPFS Project, with Professor Megan Ryan and Professor Philip Vercoe sharing information about numerous research projects to farmers, researchers, industry, and members of the general public.

The final MLP Field Day was held at UWA Farm Ridgefield on 22 October. The field day was attended by approximately 80 farmers and researchers to hear results from the project. The Australian Wool Innovation (AWI)-funded and Australian Merino Sire Evaluation Association-

Dr Bronwyn Clarke presenting in Avery's Sheering Shed on the Pingelly MLP Project.

Emeritus Professor Graeme Martin addresses the Pingelly SHS students.

MLP Project field day attendees had a chance to visit sheep involved in the trial.

Luoyang Ding, Professor Shane Maloney, Dr Meredith Guthrie, Dr Serina Hancock, Dr Hayley Norman, Dr Kelsey Pool, Associate Professor Dominique Blache and Dr Kevin Foster at UWA Farm Ridgefield.

facilitated MLP project – supported by Murdoch University, UWA, and the Federation of Performance Sheep Breeders along with the Site Committee – had run at Ridgefield since 2015.

Later in 2022, UWA representative Associate Professor Dominque Blache presented about UWA Farm Ridgefield research achievements at the WALRC Study Tour held at Cranbrook, and also joined Dr Pool and students Ms Welsh and Boland for talks at the WALRC Livestock Matters in Fremantle.

Education

Education is integral to the BPFS Project, from high school students through to Bachelor, Master's and Doctorate level. The project provides an excellent platform for practical field experience.

Throughout the year, more than 110 UWA students attended study excursions to Ridgefield or visited for research purposes. Four groups from the Professional Computing course completed and designed IT solutions for use by the BPFS Project. About 75 UWA students (from courses Pasture and Livestock Systems, Food Fibre and Fuel Security, and Clean Green and Ethical Animal Production) undertook field trips to the farm in the month of September.

Year 11 and 12 students from Pinjarra Senior High School visited the farm in July. Emerita Professor Lyn Abbott and Emeritus Professor Graeme Martin guided them on a bus tour that included research talks and taking soil samples. In August, Farm Manager Tim Watts and Farm Consultant Ashley Herbert presented a case study on sheep and cropping to approximately 80 undergraduate students.

Four Murdoch University veterinary students undertook two weeks' work experience at UWA Farm Ridgefield in 2022. Seven postgraduate students visited and utilised Ridgefield for their research projects, including:

- Eloise Boland (UWA Master's): *Heat Stress in Livestock Project* (MLA DC Project)
- Callum Connolly (UWA Master's): *Exogenous melatonin and ram sperm quality during heat stress project*
- Jessie Weller (UWA PhD): *Critical Zone research*
- Diego da Silva Turollo (UWA PhD): *Critical Zone research*
- Nathan Wells (Curtin University PhD): *How biodiverse ecosystems store more soil carbon*
- Bianca Berto (UWA PhD): *Seed Enhancement technologies research at Ridgefield Farm*
- Manish Sharma (UWA PhD): *Black Soldier Fly (BSF) Frass – a potential novel bio fertiliser to improve soil fertility, microbial diversity and yield*

UWA Farm Ridgefield also attracted several international visitors. Student Azélie Pétrowick visited from L'Institut Agro Rennes-Angers in France from September 2022 to early 2023. Master's student Feifan Wu from Yangzhou University, Yangzhou in China visited the farm in June. Dr Mubashar Hussain from the Department of Zoology, University of Gujrat, Punjab in Pakistan made trips to Ridgefield from June to early 2023. Dr Hussain conducted experiments investigating the impact of energy status and ambient temperature profiles on circadian rhythms in *Drosophila melanogaster.*

Professor Andrea Fuller from the Brain Function Research Group, School of Physiology, University of the Witwatersrand in South Africa collaborated with UWA on a project investigating the importance of circadian rhythms of temperature in Alpacas – visiting and staying on the farm in October 2022. In December, Professor Maloney visited the University of the Witwatersrand in South Africa to collaborate with Professor Fuller on research on heat stress in juvenile ostrich at the Western Cape Department of Agriculture in Oudtshoorn.

Professor Megan Ryan and Professor Philip Vercoe at the IOA stall.

Dowerin Field Days

Crowds may have been lower than expected at the Dowerin GWN7 Machinery Field Days in 2022, but spirits were high as ever at the IOA stall.

The IOA Associate Director Professor Phil Vercoe, Professor Megan Ryan, Master's student Miranda Slaven and Communications Officer Guanhao Cheng manned the stall within the DPIRD shed.

The team were delighted to greet a mix of UWA graduates, current students and other visitors who were drawn in by the vibrant and engaging display.

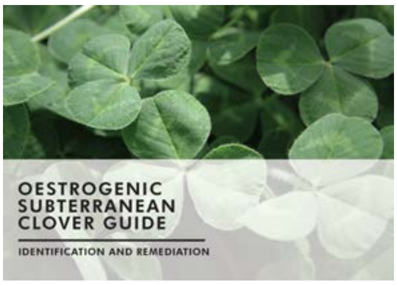
The stall featured information on the UWA Farm Ridgefield's Best Practice Farming Systems (BPFS) Project, new pathways for prospective students to study agricultural science at UWA, Emerita Professor Lynette Abbott's SOILHEALTH app, the MLA and UWA BeefLinks partnership project and more.

Throughout the two-day event, visitors were especially interested in learning what research would be on show at the Shenton Park Field Station Open Day on 23 September.

The Hon Minister for Regional Development, Agriculture and Food and Hydrogen Industry Alannah MacTiernan MLC made an early appearance in the DPIRD shed.

Ms MacTiernan spoke with Honorary Research Fellow Dr Kevin Foster from DPIRD about his new ute guide for identifying harmful oestrogenic subterranean clovers in the field.

The guides, on display at the stall, proved very popular with farmers and researchers focused on sheep fertility.



Groundwater protection & agricultural development

There was great synchronicity in the timing of Associate Professor Ofer Dahan's lecture on groundwater protection & agricultural development at UWA in September.

Just as Associate Professor Dahan took to the lectern, the Vadose-Zone Monitoring Systems (for real-time contaminant migration and water flow tracking) he developed at his company Sensoil Innovations were being shipped to UWA for the Australian CZO network (OZCZO) project.

The OZCZO project is led by IOA's Water for Food Production theme leader Associate Professor Sally Thompson.

Associate Professor Dahan is a visiting UWA Fellow from the Zuckerberg Institute for Water Research at Ben-Gurion University of the Negev in Israel.

He specialises in research on vadose zone hydrology, land use impact on groundwater quality, remediation contaminated soils, and the development of subsurface monitoring technology.

In his lecture, Associate Professor Dahan explained that achieving efficient and productive agriculture while preserving water resources quality was one of the most important challenges in water resources management.

He emphasised that the development of efficient and reliable monitoring tools was critical to optimise fertiliser application and reduce water resources pollution.

Associate Professor Dahan outside the Agriculture Lecture Theatre.

Media statements

IOA communicated its research outcomes through the media by distributing 42 media statements in agriculture and related areas in 2022. More than 21,600 people viewed IOA's media statements online. Substantial media coverage was generated in local, rural, national and international print, broadcast and online media. Overall, the IOA was referenced in 132 print news articles and 107 web/broadcast segments.

Date	Title
17 January	Unravelling how roots adapt to environmental stresses
15 February	Bud dormancy revelation could improve climate change response
21 February	New degrees to solve global food challenges
28 February	Students break down borders for crop heat and drought research
3 March	Prestigious award brings Jaco's dream of silencing crop frost damage closer
15 March	New insights into how wheat roots respond to salinity
16 March	Driving adoption of new innovations in livestock management
21 March	Investigating the impacts of applying sulphate of ammonia fertiliser with lime
23 March	What we've learned about the impact of climate change on ecosystems
1 April	Funding for research to alleviate herbicide damage to crops
5 April	Sweet rewards from honeypot ant honey study
13 April	Historic first joint PhD program between UWA and India
27 April	UWA named top university in world for Plant Science and Agronomy
28 April	Soil scientists scoop $4.34 million Federal grant
4 May	Sheep reproduction focus for Lefroy Fellow Research Seminar
12 May	Researchers abuzz over World Bee Day celebrations
13 May	Plants need light to live, but too much causes stress
16 May	Unravelling the genetic keys to improve canola crop yield
18 May	Ammoniated straw incorporation improves wheat production and soil fertility
27 May	New app provides fertile ground for soil health knowledge
2 June	Ute guide drives farmers to deal with harmful oestrogenic subclovers
10 June	The secret carbon decisions plants are making about our future
22 June	Director of the Australian Herbicide Resistance Initiative retiring
5 July	Synthetic gene circuits for precise reprogramming of plants
6 July	UWA finalists named in Premier's science awards
7 July	PhD student creates buzz with high-tech beehive monitoring system
22 July	New agricultural collaboration a boost for research and development in WA
9 August	The UWA Institute of Agriculture releases 2021 Annual Research Report
11 August	Innovative research on show at UWA Shenton Park Field Station Open Day
25 August	Rare resurrection plant may hold clues for drought tolerant crops
9 September	Engineering innovation in agriculture and ecological restoration key to new centre
12 October	International research scholarship recipient to eye apple colour
21 October	Funding to boost protein testing for researchers and industry
1 November	New Director appointed for the Australian Herbicide Resistance Initiative
2 November	Breaking new ground studying the effects of uneven crop residue distribution
4 November	Plants in space research gets funding boost
8 November	Climate change impact on wheat grain composition and quality
9 November	Five top researchers from UWA named the country's best
10 November	Mustering WA beef producers to participate in UWA research
15 November	'Never think you can't' says Highly Cited Researcher
17 November	UWA lab central to Australian-first livestock semen testing company
23 November	Review exposes untapped benefits of clover honeys

Awards and industry recognition

Name	Award
The University of Western Australia	First place in the research.com Top Plant Science and Agronomy University ranking
H/Prof Kadambot Siddique	Foreign Fellow of the Pakistan Academy of Sciences
Prof Nanthi Bolan	Choice Outstanding Academic Titles Award
Adj/Prof Jeff Camkin	International Eminent Scientist 2021 – International River-Basin Foundation and the River Water User Association (India)
Maddie Mellawage	2021 Sir Eric Smart Masters Scholarship
Wenyi Xu	2021 Sir Eric Smart Masters Scholarship
Jaco Zandberg	2022 Science and Innovation Award (Young People in Agriculture, Fisheries and Forestry prize)
Cassie Howell	Noel Fitzpatrick Medal at the Agriculture Institute of Australia (WA) Young Professionals in Agriculture Forum
Eloise Boland	WA Livestock Research Council 2022 Sponsorship
Georgia Welsh	WA Livestock Research Council 2022 Sponsorship
H/Prof Kadambot Siddique	Finalist for the WA Scientist of the Year – 2022 Premier's Science Awards, Perth
H/Prof Kadambot Siddique	Lifetime Achievement Award – 2022 Asian PGPR International Conference for Sustainable Agriculture, Malaysia
Adj/Assoc/Prof Chellapilla Bharadwaj	Eminent Scientist Award – 2022 Agrivision Convention, New Delhi
Omar Anwar	Research & Innovation Project of the Year – 2022 INCITE Awards, Perth
Dr Tsubasa Kawai	Young Researcher Award – Nagoya University
E/Prof Richard Hobbs	Honorary membership of the British Ecological Society
H/Prof Kadambot Siddique	The Australian's 2022 Research Magazine 'Top Researcher' in Botany
The University of Western Australia	Ranked first in Australia and 15th worldwide for Agricultural Sciences – Shanghai Academic Ranking of World Universities 2022
H/Prof Kadambot Siddique	2022 Clarivate Highly Cited Researcher (Agricultural Sciences and Plant & Animal Science)
E/Prof Hans Lambers	2022 Clarivate Highly Cited Researcher (Agricultural Sciences and Plant & Animal Science)
Prof Nanthi Bolan	2022 Clarivate Highly Cited Researcher (Ecology)
Prof Dave Edwards	2022 Clarivate Highly Cited Researcher (Plant and Animal Science)
Prof Jacqueline Batley	2022 Clarivate Highly Cited Researcher (Cross-Field)
Prof Ryan Lister	2022 Clarivate Highly Cited Researcher (Cross-Field)
Prof Zed Rengel	2022 Clarivate Highly Cited Researcher (Cross-Field)
Adj/Prof Jairo Palta	Gold Cross Medal from the City of Cali, Colombia
Assoc/Prof Sally Thompson	School of Engineering 2022 Mid-Career Research Award
Dr Bede Mickan	UWA School of Agriculture and Environment 2022 Outstanding Contributions to Student Learning
Dr Joanna Melonek	Vice-Chancellor's Award for Research Impact and Innovation
Prof Ian Small	Vice-Chancellor's Award for Research Impact and Innovation
Prof Peter Batt	Honorary member of the International Society of Horticultural Science
Riley Faulds	2023 WA Rhodes Scholar

New postgraduate research students

Name	Topic	School	Supervisor/s	Funding Body
Jaco Zandberg	Multi-omic analysis of the canola-blackleg interaction	School of Biological Sciences	Prof Jacqui Batley Dr Phillip Bayer Dr Nicolas Taylor	Co-funded University Postgraduate Award
Samantha Harvie	Measuring the protein storage efficiency during wheat grain development to optimise nitrogen applications	School of Molecular Sciences	Prof Harvey Millar Dr Hui Cao Dr Katharina Belt	Grains R&D Corporations Postgraduate Scholarship Sir Eric Smart Scholarship for Agriculture Research
Audrey Tascon	The demand and supply of non-market value information	UWA School of Agriculture and Environment	Dr Abbie Rogers Prof Michael Burton	Research Priorities Fund University Postgraduate Award
Callum Connolly	Preliminary measurements of sperm quality in Ridgefield rams for future projects	School of Human Sciences	Prof Shane Maloney Assoc/Prof Dominique Blache Dr Kelsey Pool Dr Serina Hancock	The Edward Moss PhD Scholarship in Agriculture
James O'Connor	Food waste valorisation products as a nutrient source and carbon amendments	UWA School of Agriculture and Environment	Prof Nanthi Bolan H/Prof Kadambot Siddique Dr Bede Mickan Assoc/Prof Matthias Leopold	University Postgraduate Award
Jessie Weller	Critical Zone architecture influences water storage, fate, and transport within a deeply weathered lateritic landscape in Western Australia's wheatbelt	UWA School of Agriculture and Environment	Assoc/Prof Matthias Leopold Assoc/Prof Sally Thompson	RTP Domestic Fees Offset
Luca Agostinelli	The neuronal mechanisms involved in the generation and modulation of episodic ultradian events in body temperature regulation	UWA School of Agriculture and Environment	Assoc/Prof Jennifer Rodger Dr Alexander Tangs Assoc/Prof Domonique Blache	University Postgraduate Award
Joanne D. Caguiat	Syntenic characterization and validation of drought tolerance genes in rice, wheat, barley, and maize crops	UWA School of Agriculture and Environment	Dr Guijun Yan Dr Hui Liu	Department of Science and Technology - Science Education Institute (DOST-SEI) Foreign Graduate Scholarship Philippine Rice Research Institute
Xavier Caguiat	Genetic and molecular dissection of glyphosate tolerance in wheat (Triticum aestivum L.)	UWA School of Agriculture and Environment	Dr Guijun Yan Dr Hui Liu	Department of Science and Technology-Science Education Institute (Philippines) Global Innovation Linkage
Yan Ai	How and why glyphosate, and atrazine application affect White Leaf Spot (Neopseudocercosporella capsellae) epidemics, on herbicide resistant canola	UWA School of Agriculture and Environment	Prof Martin Barbetti Prof Guijun Yan Dr Ming Pei You	Self-funded
Nuraizat Abidin	Understanding the interaction of Turnip Mosaic Virus (TUMV) with blackleg disease (Leptosphaeria maculans) in canola	UWA School of Agriculture and Environment	Prof Martin Barbetti Dr Roger Jones Dr Ming Pei You	Brunei Darusseleum Government Sponsorship University Postgraduate Award
Garima	Farm to Port: An Optimisation Model to Navigate Through Heterogenous Agents' Interactions in Agri-food Supply Chains	UWA Business School	Assoc/Prof Doina Olaru H/Prof Kadambot Siddique	UWA Scholarship for International Research Fees University Postgraduate Award

New research grants

Title	Funding Period	Funding Body	Investigator/s
Effect of mineral magic amorphous silica on moisture retention, wheat and canola growth, nutrition and yield in sandy soils	2022-2024	Mineral Magic	H/Prof Kadambot Siddique, Dr Zakaria Solaiman, Prof Nanthi Bolan
Alleviating herbicide damage to crops by using fulvate and manganese	2022-2025	ARC Linkage	Prof Zed Rengel, Prof Petra Marschner, Paul Storer
Unleashing the hidden chemical diversity in Australian fungi	2022-2024	ARC Linkage	Dr Yit-Heng Chooi, Assoc/Prof Andrew Piggott, Dr Ernest Lacey
Engineering safer pastures for livestock	2022-2026	ARC Linkage	Prof Jacqueline Batley, Dr Yit-Heng Chooi, Prof Philip Vercoe, Prof Megan Ryan, Dr Derek Woodfield
Role of Si in improving wheat growth in acid soils	2022-2022	Maxsil	Prof Zed Rengel
The potential of biomineral fertilisers to increase soil carbon sequestration	2022-2026	MLA	Dr Zakaria Solaiman, H/Prof Kadambot Siddique, Prof Phil Vercoe, Prof Nanthi Bolan
Setting new standards for honey bee nutrition in Australian bee stock	2022-2025	AgriFutures Australia	Dr Julia Grassl
Quantifying nitrogen losses and the effect on crop productivity and greenhouse gas emissions from the application of lime and sulphate of ammonia fertiliser under Western Australian farming systems	2022-2023	GRDC	Assoc/Prof Louise Barton , Prof Zed Rengel, Paul Damon, Dr Fiona Dempster, Assoc/Prof Matthias Leopold
Adopting HPTLC honey testing for industry use	2022-2023	CRC for Honey Bee Products	Prof Cornelia Locher
Australian seed scaling initiative: Large-scale deployment of diverse, enhanced seed mixes using customised precision seeding technologies	2022-2025	CRC Programmes	Dr Todd Erickson, Monte Masarei, Assoc/Prof Andrew Guzzomi
Maintenance of high plant diversity in phosphorus-impoverished ecosystems	2022-2024	ARC Discovery	E/Prof Hans Lambers, Dr Kosala Ranathunge, Prof Treena Burgess
BeefLinks: Producer insights for adoption outcomes across WA BeefLinks	2021-2024	MLA	Dr Fiona Dempster, Prof Phil Vercoe, Dr Fay Rola-Rubzen , Ms Tammie Harold, Assoc/Prof Marit Kragt, Dr Abbie Rogers, Dr Amin Mugera
Engineered clay-polysaccharide nanocomposites for efficient nutrient delivery	2022-2026	ARC Linkage	Prof Nanthi Bolan, Prof Ajay Karakoti, Prof Ajyan Vinu
Soil biological mechanisms underpinning the effects of biological amendments on soil health, productivity and resilience	2022-2025	Federal Government Soil Science Challenge	E/Prof Lynette Abbott, H/Prof Kadambot Siddique, Prof Nanthi Bolan, Dr Sasha Jenkins, Dr Zakaria Solaiman, Dr Bede Mickan, Marit Kragt, Assoc/Prof Louise Barton, Assoc/Prof Matthias Leopold, The University of Adelaide, Western Sydney University
Differential solidification of steel slag to create a fertiliser co-product	2023	ARC Linkage	Assoc/Prof Tom Honeyands, Prof Brian Monaghan , Prof Nanthi Bolan, Dr Subhasish Mitra, Dr Thi Bang Tuyen Nguyen, Prof Geoffrey Evans , Dr Damien O'Dea
How nutrition affects key life-history traits in humans including immune function, reproductive health, physical appearance, and healthy ageing	2023	Discovery Early Career Researcher Award	Dr Yong Zhi Foo
Linking phenotyping with genotyping to discover novel genes and QTLs regulating important root architecture traits in soybean germplasm	2022	UWA Research Collaboration Awards	Dr Yinglong Chen, Dr Gustavo Boitt

Title	Funding Period	Funding Body	Investigator/s
Unlocking new genetic systems for hybrid breeding in wheat	2023	UWA Research Collaboration Awards	Dr Joanna Melonek, Prof Ian Small
Parameter setting for plant growth for future space flight or Mars/Lunar installations	2023	UWA Research Collaboration Awards	Prof Harvey Millar
Implementing improved vineyard floor management for premium grape production in a warm and dry Mediterranean climate	2022-2023	Grower Group Alliance	Dr Joanne Wisdom, Dr Nik Callow, Daniel Kidd, Dr Caitlin Moore
Soil biological mechanisms underpinning the effects of biological amendments on soil health, productivity and resilience	2022-2025	Department of Agriculture, Water and the Environment	Dr Sasha Jenkins, E/Prof Lynette Abbott, Prof Nanthi Bolan, H/Prof Kadambot Siddique, Assoc/Prof Marit Kragt, Dr Zakaria Solaiman, Dr Bede Mickan, Assoc/Prof Matthias Leopold, Assoc/Prof Louise Barton, Ian Waite
Australian Research Council Centre of Excellence in Plants for Space	2022-2025	Australian Government	Prof Harvey Millar, Prof Ryan Lister , Prof Ian Small, University of Adelaide leads 38 partner organisations
Novel agronomic practices to achieve productive and profitable viticulture in northern Australia	2022-2026	Cooperative Research Centre for Developing Northern Australia	Assoc/Prof Michael Considine
Determining the impacts of grazing oestrogenic clovers on cattle fertility	2022-2025	DPIRD	Prof Phil Vercoe, Dr Tim Watts, Jessica Shilling, Dr Kevin Foster, Assoc/Prof Dominique Blache
Building an advanced genomics platform for Australian horticulture	2022-2027	Horticulture Innovation Australia Ltd Ex Murdoch	Assoc/Prof Parwinder Kaur
Innovation in crop weed control	2022-2023	GRDC	Dr Michael Walsh, Assoc/Prof Andrew Guzzomi
Intensified and Diverse Farming Systems for Timor-Leste (AI-Com 2)	2022-2027	ACIAR	Assoc/Prof Louise Barton, E/Prof William Erskine, Assoc/Prof Matthias Leopold, Prof Nanthi Bolan, Assoc/Prof James Fogarty, Assoc/Prof Fay Rola-Rubzen
Agricultural Innovations for Communities – Building new technologies for sustainable and profitable sub clover seed harvesting	2022-2025	AgriFutures Australia	Assoc/Prof Andrew Guzzomi, Assoc/Prof Phillip Nichols, Prof Megan Ryan, Dr Wesley Moss, Ruby Wiese, Dr Joanne Wisdom

New IOA appointments

Name	Position	Date
Prof Madan Pal Singh	Adjunct Professor	1 February
Prof Meththika Vithanage	Adjunct Professor	6 February
Dr Nathan Craig	Adjunct Lecturer	1 March
Dr Kevin Foster	Honorary Research Fellow	8 March
Dr Yufeng Zou	Adjunct Associate Professor	7 April
Dr Lukasz Kotula	Honorary Research Fellow	30 June
Dr Roopali Bhoite	Adjunct Lecturer	25 August
Dr Shiv Bolan	Research Fellow	15 September

The UWA Institute of Agriculture Staff

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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.

Professor Anna Nowak
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2022 Publications

Peer Reviewed Journals

1. Abbas G, Rehman S, Saqib M, Amjad M, Murtaza B, Siddiqui MH and Chen Y (2022). Resistance to NaCl salinity is positively correlated with iron and zinc uptake potential of wheat genotypes. *Crop & Pasture Science* **73**: 546-555 doi: 10.1071/CP21478
2. Abdul R, Muhammad F, Aman U, Ahmad N, Moeen UDM and Babar S (2022). Seed priming with zinc sulfate and zinc chloride affects physio-biochemical traits, grain yield and biofortification of bread wheat (*Triticum aestivum*). *Crop & Pasture Science* **73** 449-460 doi: 10.1071/CP21194
3. Abideen Z, Cardinale M, Zulfiqar F, Koyro H-W, Rasool SG, Hessini K, Darbali W, Zhao F and Siddique KHM (2022). Seed Endophyte bacteria enhance drought stress tolerance in Hordeum vulgare by regulating, physiological characteristics, antioxidants and minerals uptake. *Frontiers in Plant Science* **13:** 980046 doi: 10.3389/fpls.2022.980046
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10. Al-lami HFD, You MP and Barbetti MJ (2022). Novel resistances provide new avenues to manage Alternaria leaf spot (*Alternaria brassicae*) in canola (*Brassica napus*), mustard (*B. juncea*) and other Brassicaceae crops. *Plant Disease* doi: 10.1094/PDIS-05-22-1153-RE
11. AlMulla A, Dahlawi S, Randhawa M, Zaman Q, Chen Y and Faraj T (2022). Toxic metals and metalloids in Hassawi brown rice: Fate during cooking and associated health risks. *International Journal of Environmental Research and Public Health* **19** doi: 10.3390/ijerph191912125
12. Al-Shwaiman HA, Shahid M, Elgorban AM, Siddique KHM and Syed A (2022). Beijerinckia fluminensis BFC-33, a novel multi-stress-tolerant soil bacterium: Deciphering the stress amelioration, phytopathogenic inhibition and growth promotion in *Triticum aestivum* (L.). *Chemosphere* **295** doi: 10.1016/j.chemosphere.2022.133843
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Acronyms

ACIAR	Australian Centre for International Agricultural Research
AFB	American foulbrood
AfN	Accounting for Nature
AGT	Australian Grain Technologies
AHRI	Australian Herbicide Resistance Initiative
AIA	Ag Institute of Australia
AIM	Australian Institute of Management
AIWC	Australia India Water Centre
ALBA	Annual Legume Breeding Australia
AM	Arbuscular mycorrhizal
ANSTO	Australian Nuclear Science and Technology Organisation
ARC	Australian Research Council
ARF	Agrarian Research Foundation
ASI	Ammoniated straw incorporation
AWI	Australian Wool Innovation
BASF	Badische Anilin und Soda Fabrik
BAU	Bangladesh Agricultural University
BCCM	Business Council of Co-operatives and Mutuals
BI	Straw-derived biochar incorporated into the soil
BICWA	Bee Industry Council of Western Australia
BPFSP	Best Practice Farming Systems Project, UWA Farm Ridgefield
BSF	Black soldier fly
CA	Conservation Agriculture
CAAS	Chinese Academy of Agricultural Sciences
CAS	Chinese Academy of Sciences
CASI	Conservation Agriculture-based Sustainable Intensification
Cd	Cadmium
CEI: AgER	Centre for Engineering Innovation: Agriculture & Ecological Restoration
CF	Carbon footprint
CIAT	The International Center for Tropical Agriculture
CIMMYT	International Wheat and Maize Improvement Center
CitWA	Citizen of Western Australia
CME	Co-operative and Mutual Enterprise
CN30	Carbon Neutral 2030
CO_2	Carbon dioxide
COGGO	The Council of Grain Growers Organisations Limited
CRC	Cooperative Research Centre
CSAP	Climate-Smart Agricultural Practices
CSBP	Cuming Smith British Petroleum and Farmers Limited
CSC	Chinese Scholarship Council
CSI	Conventional straw incorporation
CSIRO	Commonwealth Scientific and Industrial Research
CWSS	Centre for Water and Spatial Science
CZO	Critical Zone Observation
DEFRA	UK Department of Environment Food and Rural Affairs
DHA	Dihydroxyacetone
DNA	Deoxyribonucleic Acid
DPIRD	Department of Primary Industries and Regional
DWER	Department of Water and Environmental Regulation
ECU	Edith Cowan University
EIAR	Ethiopian Institute of Agricultural Research
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
FFLI	Food, Fibre and Land International
FISPP	Fellow of the Indian Society for Plant Physiology
FNAAS	Foreign Fellow of the Indian National Academy of
FTA	Free Trade Agreements
FTSE	Fellow of the Australian Academy of Technological Sciences
GHG	Greenhouse gas
GIL	Global Innovation Linkages
GIWA	Grains Industry Association of WA
GoP	Operational stomatal conductance
GPS	Global Positioning System
GRDC	Grains Research and Development Corporation
GWAS	Genome wide association studies
HPPD	Hydroxyphenyl pyruvate dioxygenase
IAB	Industry Advisory Board
ICA	International Co-operative Alliance
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IMB	Institute Management Board
IOA	The UWA Institute of Agriculture
IWA	International Water Association
KGF	Krishi Gobeshona Foundation
LA	Lauric acid
LiDAR	Light Detection and Ranging
LLL	Laser Land Leveller
LPTC	Low-P tolerance coefficients
MAF	Ministry of Agriculture and Fisheries, East Timor
MAS	Marker-assisted Selection
MDC	MLA Donor Company
MGO	Methylglyoxal
MLA	Meat and Livestock Australia
MLP	Merino Lifetime Productivity
MTA	Marker-trait associations
N	Nitrogen
NAAS	National Academy of Agricultural Sciences, India
NACRA	North Australian Crop Research Alliance
NaCRRI	National Crops Resources Research Institute, Uganda
NARC	Nepal Agricultural Research Council
NcA	Natural Capital Accounting
NESP	National Environmental Science Programme
NILs	Near isogenic lines
NPZ	Norddeutsche Pflanzenzucht
NSU	North South University
NSW DPI	New South Wales Department of Primary Industries
NSW	New South Wales
OCS	Optimal Contribution Selection
P	Phosphorus
PC	Percentage yield change
PFT	Plant functional types
PTF	Pedotransfer functions
PTM	Post-translational modifications
QLD	Queensland
QTL	Quantitative trait locus
R&D	Research and Development
RDE&A	Research, Development, Extension and Adoption
RTP	Research Training Program scholarship
SAgE	UWA School of Agriculture and Environment
SAGI	Statistics for the Australian Grains Industry
SAI	Sustainable Agricultural Intensification
SARDI	South Australian Research and Development Institute
SDG	United Nations Sustainable Development Goal
Si	Silicon
SME	Small and medium enterprises
SOA	Sulphate of ammonia
SOCS	Soil organic carbon sequestration
SRFSI	Sustainable and Resilient Farming Systems Intensification
STI	Stress tolerance index
SWCP	Soil and water conservation practices
SWS	Soil water storage
UAF	University of Agriculture, Faisalabad, Pakistan
UIFS	UWA International Fee Scholarship
UNE	University of New England
UNSW	University of New South Wales
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
VIC	Victoria
VMS	Vadose-zone Monitoring System
WA	Western Australia
Zn	Zinc
ZNE	Zero Net Emissions
ZNEAg CRC	Zero Net Emissions from Agriculture CRC

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