THE UNIVERSITY OF WESTERN AUSTRALIA | Institute of Agriculture

Annual Research Report 2021

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 Communication 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 Western Australia and relevant to national and international issues.

Font cover image: Drone photo of UWA AHRI research in Cunderdin WA, using LiDAR for weed identification.
Photo: Roberto Lujan Rocha

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The UWA Institute of Agriculture Annual Research Report 2021

Director's overview

On behalf of The University of Western Australia (UWA), I am pleased to present the Annual Research Report 2021 for The UWA Institute of Agriculture (IOA).

In a year that Western Australia broke all previous records and harvested 24 million tonnes of grains, it is fitting that our Institute also enjoyed an exceptional 12 months of growth and yield. Our affiliated researchers and their collaborators contributed more than 420 journal articles, books and book chapters in 2021 – making this Annual Research Report our largest on record for the second year running. We also celebrated numerous academics named on the annual Highly Cited Researchers list, which contributed to our status as first in Australia and 16th in the world for Agricultural Sciences in the 2021 Academic Ranking of World Universities (ARWU).

Collaborative and multidisciplinary research and development activities were expertly guided by the leaders of our six Research Themes. These Themes were revised and updated for the development of our Strategic Plan 2021-2025, which was published in January and marked an exciting new, future-focused strategy for IOA. Interest in UWA's agricultural research, development and training activities continued to grow throughout 2021. Public engagement with IOA increased significantly online; with our LinkedIn followers quadrupling and Twitter audience near doubling in size. Thirty-two media statements were distributed, generating excellent coverage in WA, interstate, and international media.

Through our communications and events activities, we improved upon our engagement with industry, farmer groups, collaborators, funding bodies, and alumni. Starting with the hugely popular Pingelly Astrofest in March, IOA hosted or contributed to 14 events in 2021. These public events were an outstanding opportunity to promote UWA's research outputs in agriculture and related areas, educational opportunities, state-of-the-art facilities and more. A personal highlight was attending the UWA Farm Ridgefield Open Day, which celebrated the many innovative research projects underway at the farm, as well as the long-standing and productive working relationship between UWA and the Pingelly community.

I wish to take this opportunity to acknowledge and congratulate 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, continued support and hard work throughout 2021. This Annual Research Report is a credit to you all.

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

The Industry Advisory Board (IAB) is one of the integral pillars that sustain and strengthen the foundations of The UWA Institute of Agriculture. Our Board, comprised of passionate farmers and representatives from the agriculture industry, provide advice and support that enhances the value of IOA to the rural and regional industries of WA, Australia and beyond.

Congratulations to IOA for launching its forward-thinking Strategic Plan 2021-2025 in January. Having attended the full-day workshop to develop this comprehensive document in late 2020, I am pleased to see how well it has been received. In 2021, we welcomed two new members to our Board: CSIRO Senior Principal Research Scientist Dr Hayley Norman and Elders senior agronomist Belinda Eastough, who operates a large grain farming enterprise in the Geraldton region. On behalf of the IAB, I extend my gratitude to former board members CSIRO Agriculture and Food Deputy Director Michael Robertson and Planfarm Consultant Dani Whyte for their many years of dedication and support.

The 15th annual Industry Forum in July was among the many highlights of our 2021 calendar. It was wonderful to see so many members of the research, industry and farming communities come together to explore how we can future-proof WA agriculture and maximise opportunities for a resilient food production system. The IAB played a major role in selecting this topic and identifying the expert speakers. In September, members of our Board thoroughly enjoyed learning more about UWA research activities related to sustainable pastures and fodder at the UWA Farm Ridgefield Open Day. The following month, IAB member Bruce Mullan joined key stakeholders at a workshop to develop a new Strategic Plan 2022-27 for the Future Farm 2050 Project.

The IAB will continue to build upon its partnership with IOA to achieve our shared goals. Thank you to members of the IAB, all IOA contributors, and Director Hackett Professor Kadambot Siddique and his team.

Dr Terry Enright
Chair of the IOA Industry Advisory Board

Much of what we aspire to achieve at The University of Western Australia is exemplified by the activities of The UWA Institute of Agriculture.

There are many ways of measuring success. We can refer to our exceptional 2021 rankings – with Agricultural Science at UWA ranking at 16th in the world and top in Australia. We can look at industry engagement, which is something IOA does incredibly well through its Industry Advisory Board and participation in public events such as the Dowerin Field Days. When we consider our highly cited authors and research funding success, many of our celebrated academics have roots in IOA. We can also look at the many PhD students working within the Institute, being immersed in an environment of excellence and with opportunities to discuss and present their work with leading researchers. On all these grounds, IOA demonstrates a critical mass that is contributing strongly to UWA, to our next generation of researchers, to our community, and to the world.

Building research capacity is a priority for UWA. Through open minds and collaboration, IOA brings researchers and leaders from a diverse set of disciplines together to focus on several big picture priorities such as sustainability, food security, social impact, big data and climate change. IOA also fosters industry partnerships and bolsters the value of our research to the community. Its close relationships between grower groups, the agriculture industry, government bodies, fellow UWA institutes and schools is critical in ensuring that the most impactful research is done.

Regular communication and translation of research through IOA's media statements, social media, events and publications – this Annual Research Report 2021, in particular – forms an impressive record of the Institute's activities and achievements. These channels help stimulate discussion and lead to positive outcomes for the University and agricultural sector. Thank you and congratulations to everyone affiliated with IOA for your hard work and dedication in 2021.

Professor Anna Nowak
Acting Deputy Vice-Chancellor (Research)

The University of Western Australia

UWA PhD candidate Daniel Kidd and Research Associate Dr Joanne Wisdom with field trials at the UWA Shenton Park Field Station.

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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 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 this 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 thermal tolerance (frost and heat), crop water use efficiency, use of drones, 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. Crop diseases are also researched. 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. At all times, we are cognisant of the needs of the industries and farmers who will ultimately apply our research outcomes to their farming systems.

Theme Leaders

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PhD candidate Mahtab Omidvari in a UWA glasshouse.

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 R. 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*) not only greatly diminishes forage and seed yield but stimulates production of detrimental phytoestrogens in annual *Medicago* spp. pastures.

Initial studies involving 35 *P. medicaginis* isolates highlighted how differences between isolates were a strong determinate of disease severity and phytoestrogen production in annual *Medicago* spp. There was a significant positive relationship of disease incidence and severity parameters with both coumestrol and 4′-O-methylcoumestrol contents. Levels of phytoestrogens in stems ranged up to almost 2000 mg/kg for coumestrol and more than 400 mg/kg for 4′-O-methylcoumestrol, with up to a 15-fold increase in coumestrol from infection of *P. medicaginis*.

These levels are highly significant as even levels as low as 25 mg/kg dry weight of coumestrol in annual *Medicago* spp. can adversely impact sheep fertility. The study highlighted that the intrinsic ability of a particular cultivar to produce phytoestrogens in the absence of the pathogen, and its comparative ability to produce phytoestrogens in the presence of the *P. medicaginis*, are both important and highly relevant to developing new annual *Medicago* spp. cultivars that offer improved disease resistance and better animal reproductive outcomes. For example, although, cv. Serena was most susceptible to *P. medicaginis* and produced the highest levels of phytoestrogens in the presence of *P. medicaginis*, cv. Zodiac contained the highest levels of phytoestrogens in comparison with other cultivars in the absence of *P. medicaginis*.

Annual *Medicago* cv. Sava showing typical Phoma Black Stem disease symptoms.

A second more detailed study involving 16 different cultivars representing eight different annual *Medicago* species, highlighted how Phoma Black Stem severity and phytoestrogen production in annual *Medicago* spp. is especially determined not just by pathogen isolate, but principally by the interaction of pathogen isolate with cultivar.

Levels of coumestrol and 4′-O-methylcoumestrol ranged up to greater than 640 and greater than 85 mg/kg, respectively, and there was significant correlation of disease incidence/severity factors with both coumestrol and 4′-O-methylcoumestrol. Cultivar Jemalong was least-responsive and Paragosa and Sava most-responsive to coumestrol production following *P. medicaginis* inoculation, with an approximate two and 30-fold increases, respectively. Coumestrol in inoculated Paragosa increased to more than 370 mg/kg in comparison with from 0 mg/kg in controls. These findings are of critical importance towards developing less disease-susceptible and more productive annual *Medicago* spp. producing less detrimental phytoestrogens. Least susceptible cultivars like Tornafield and Caliph can be used to manage yield loss from Phoma Black Stem and least responsive cultivars to phytoestrogen production like Caliph to reduce phytoestrogen production.

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

Protecting Ethiopian lentil crops

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 new five-year ACIAR project led by UWA addresses the biotic stresses – viruses, foliar and soil-borne diseases – that threaten Ethiopian lentil crops.

In the mid-highlands of Ethiopia, lentils are one of the foundational legume rotation crops for 600 thousand households dependent on cereal-based farming systems (wheat, barley and tef). Lentils are an important part of the Ethiopian diet and a high value cash crop with great cultural importance. Lentils contribute up to 50–100 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, generating 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, 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 farming practices considering crop protection, genetics, agronomy, livestock nutrition and farming system analysis. Critical to this will be the adoption of the new practices for management of 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 in particular.

Baskets of dried lentils in a market.

A Zoom screenshot during the project launch in October 2021.

Beyene Bitew Eshete and Professor Martin Barbetti in labs in Debre Birhan.

Faba bean gall pathogen *Physoderma viciae*: new primers reveal its puzzling 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]

Collaborating organisations: [1]UWA; [2]Debre Birhan Agricultural Research Centre; [3]ICARDA

This research project earlier confirmed the pathogen *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. Faba bean is of critical importance for food security in Ethiopia, and the disease is especially devastating for this East African community. It is also known to attack other crop (e.g., field pea) and forage (e.g., clover) legumes growing nearby and poses a serious international biosecurity risk for its potential to be accidentally introduced into other countries, including Australia.

The first two pairs of primers, 'Physo 1' that readily detects *P. viciae* and another pair 'Physo D', that clearly separates the identity of *P. viciae* from the common and confounding presence of *Didymella/Phoma* spp. have been developed.

Additionally, these new primers highlight, for the first time, the almost universal, but symptomless, presence of members of the field pea Ascochyta blight pathogen complex within faba bean infested by *P. viciae*. Further, it provides the first plausible explanation for the widespread occurrence of the field pea Ascochyta blight pathogen complex even in situations where there has been an absence of field pea cropping for many years. Finally, it highlights the need for further evaluation of the occurrence and role of seemingly 'symptomless' legume pathogens in Ethiopia and worldwide, both in relation to faba bean crops and, more widely, across situations where crop and/or forage legumes are grown in rotation, or as mixed crop types such as faba bean/field pea mixtures, or in proximity.

This research is supported by ACIAR and UWA.

Faba bean plants in the field severely affected by faba bean gall disease.

Sequencing historical crop virus isolates

Project team: Adjunct Professor Roger Jones[1] (project leader; roger.jones@uwa.edu.au), Dr Ian Adams[2], Dr Adrian Fox[2], Professor Neil Boonham[3], Emeritus Professor Adrian Gibbs[4], Professor Cesar Fribourg[5], Dr Mohammad Hajizadeh[6], Dr Segundo Fuentes[7], Ana Perez[7], Dr Jan Kreuze[7]

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

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. Sequencing these historical isolates helps avoid unnecessary repetition of research when, due to their absence from the GenBank database, subsequent investigations fail to connect a virus being studied with previous research on the same virus, resulting in errors in virus nomenclature. It also helps with studies identifying when different virus lineages diverged in the past giving rise to new lineages or even new viruses. Another important outcome of historical isolate sequencing is that it helps reveal the extent of virus population changes within a world region over long periods.

In 2021, the phylogenetics of potato virus X (PVX) was studied. This virus occurs worldwide and causes an important global potato disease. Complete PVX genomes were obtained from 326 new isolates from Peru, which is within the potato crop's main domestication centre, 10 from historical PVX isolates from the Andes (Bolivia, Peru) or Europe (UK), and three from Africa (Burundi). These new genomes were compared with 49 already published PVX genomic sequences.

A phylogeny of the non-recombinant sequences found two major (I, II) and five minor (I-1, I-2, II-1, II-2, II-3) phylogroups, which included 12 statistically supported clusters. Analysis of 488 coat protein (CP) gene sequences, including 128 published previously, gave a completely congruent phylogeny. Among the well-sampled minor phylogroups (n > 40 isolates), I-2 and II-3 only contained Andean isolates, I-1 and II-2 were of both Andean and other isolates, but all of the three II-1 isolates were European. I-1, I-2, II-1 and II-2 all contained biologically typed isolates. Population genetic and dating analyses indicated that PVX emerged after potato's domestication 9000 years ago and was transported to Europe after the 15th century. Major clusters A–D probably resulted from expansions that occurred soon after the European potato late-blight pandemic of the mid-19th century.

Genetic comparisons of the PVX populations of different Peruvian Departments found similarities between those linked by local transport of seed potato tubers for summer rain-watered highland crops, and those linked to winter-irrigated crops in nearby coastal departments.

Comparisons also showed that, although the Andean PVX population was diverse and evolving neutrally, its spread to Europe and then elsewhere involved population expansion. PVX forms a basal Potexvirus genus lineage but its immediate progenitor is unknown. Establishing whether PVX's entirely Andean phylogroups I-2 and II-3 and its Andean recombinants threaten potato production elsewhere requires future biological studies.

This research is supported by 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, Bill &Melinda Gates Fund, University of Kurdistan (Iran), Saga University (Japan), National Agrarian University (Peru), DPIRD, and UWA.

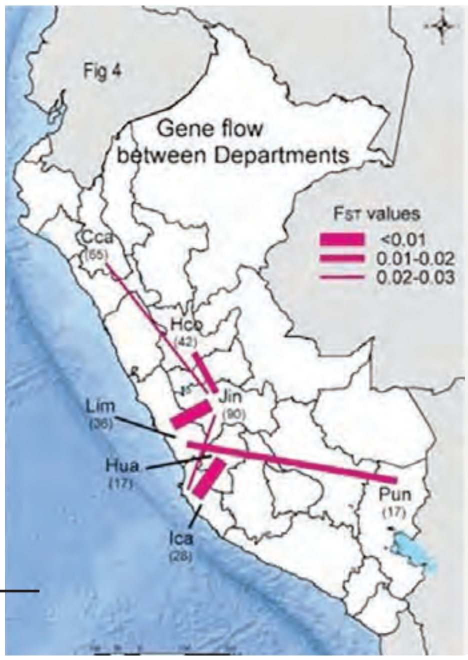


Illustration showing the most significant genetic linkages between the potato virus X populations of different Peruvian Departments. Linkages are indicated by their FST values.

Typical symptoms caused by potato virus X in a potato leaf.

Increasing virus disease epidemics threaten Australia's cereal and oilseed crops

Project team: Adjunct Professor Roger Jones[1] (project leader; roger.jones@uwa.edu.au), Dr Benjamin Congdon[2], Dr Murray Sharman[3], Dr Piotr Trebicki[4], Dr Solomon Maina[4]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]Queensland Department of Agriculture and Fisheries; [4]Agriculture Victoria, Department of Jobs, Precincts and Regions

This research project resulted in a comprehensive review of virus disease research in Australia's cereal and oilseed crops since the 1950s. Virus epidemics in crops around Australia can drastically reduce the infected crop's seed yield and seed quality, causing serious financial hardship to growers and shortages in produce supply. Virus-induced crop losses ranged from minor to complete crop failure and were increasing in magnitude. According to lead researcher Adjunct Professor Roger Jones, a comprehensive review of the biology, epidemiology and management of damaging virus diseases of these critically important crops was therefore both overdue and timely.

All 31 viruses known to infect the diverse range of cereal and oilseed crops grown in the continent's temperate, Mediterranean, subtropical and tropical cropping regions were included in the review. Seven of these viruses are currently of major economic importance. Depending on the virus concerned and climatic conditions, the most important virus vectors that spread each of the 31 viruses were aphids, whiteflies, thrips, leafhoppers or mites.

Climate change, induced climate instability and extreme weather events have altered virus epidemiology and vector distributions and decreased the effectiveness of virus and vector control measures. Effective virus management is being influenced by increased insecticide resistance in key insect and mite vectors, the development of resistance-breaking virus strains, and insufficient industry awareness of virus diseases. Further, even more damaging crop viruses and more-efficient virus vector species are also likely to spread to Australia from other world regions.

The review recommends that future research into virus diseases in Australian cereal and oilseed crops should be adequately resourced to ensure they are protected.


Wheat showing wheat streak mosaic virus disease symptoms.

Potato virus Y biological strain group Y^{D}: Hypersensitive resistance genes elicited and phylogenetic placement

Project team: Adjunct Professor Roger Jones[1] (project leader; roger.jones@uwa.edu.au), Professor Martin Barbetti[1], Dr Ian Adams[2], Dr Adrian Fox[2]

Collaborating organisations: [1]UWA; [2]FERA Science Ltd, UK

Potato now ranks as the world's fourth most important staple food crop after maize, wheat, and rice; and the third most important in food-insecure developing countries. Potato virus Y (PVY) disrupts healthy seed potato production and causes tuber yield and quality losses globally. The disease it causes constitutes the most important potato virus disease worldwide. PVY's variants consist of strain groups defined by potato hypersensitive resistance (HR) genes and phylogroups defined by sequencing.

When Australian PVY isolate PP from cultivar Peruvian Purple was inoculated to potato cultivar differentials with HR genes, the phenotypic pattern obtained resembled that caused by strain group PVYD isolate KIP1 from cultivar Kipfler which is also from Australia; Peruvian Purple and Kipfler tubers resemble those of native potato land races growing in the potatoes' Andean domestication center. Putative HR gene Nd was proposed previously to explain the unique HR phenotype pattern found when potato cultivar differentials were inoculated with PVYD.

However, an alternative explanation was that PVYD elicits HR with both of genes Nc and Ny. To establish which gene(s) it elicits, isolates KIP1 and PP were inoculated to F1 potato seedlings from: (i) crossing cultivars Kipfler or White Rose with cultivar Ruby Lou, and (ii) self-pollinated cultivars Desiree and Ruby Lou; where Kipfler is susceptible (S) but White Rose, Desiree and Ruby Lou all develop HR. With both isolates, the HR:S (S=susceptible) segregation ratios obtained fitted 5:1 for Kipfler x Ruby Lou, 11:1 for White Rose x Ruby Lou, and 3:1 for Desiree. Those for Ruby Lou were 68:1 (isolate PP) and 52:0 (isolate KIP1). Since potato is a tetraploid, these ratios suggest PVYD elicits HR with Ny from Ruby Lou (duplex condition) and Desiree (simplex condition), and Nc from White Rose (simplex condition), but provide no evidence that Nd exists. Therefore, these studies revealed that PVYD isolates elicit an HR phenotype in potato cultivars with either of two HR genes, Nc or Ny, so putative gene Nd can be discounted.

A complete genome of isolate PP was obtained by high throughput sequencing. After removal of its short terminal recombinant segment, it was subjected to phylogenetic analysis together with 28 complete non-recombinant PVY genomes. It fitted within the same minor phylogroup sub-clade as KIP1.

This sub-clade constitutes the most basal divergence within overall major phylogroup PVYO. Since its date of origin is calculated at 1458CE, it diverged before the Spanish 1526 invasion of Peru so was present before the potato crop was introduced from the Andean region to other continents.

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

Foliage of a White Rose x Ruby Lou cross seedling plant showing mild mosaic symptoms (susceptible phenotype) caused by inoculation with PVY isolate PP-infected leaf sap.

Foliage of potato cultivar White Rose x Ruby Lou cross seedling plant showing necrotic spot local lesions (Hypersensitive phenotype) caused by inoculation with PVY isolate PP-infected leaf sap.

Paddock level herbicide resistance management for Western growers and advisors

Project team: Dr Fiona Dempster[1], Dr Roberto Busi[1] (project leader; roberto.busi@uwa.edu.au), Dr Rick Llewellyn[2], Dr Masood Azeem[2]

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

Resistance testing by AHRI in the field.

Managing herbicide resistant weeds in cropping systems is a growing issue for the industry. Herbicide resistance testing services allow growers and their agronomy advisors to submit weed seed samples and confirm the resistance status of the sampled population to a range of herbicides. The economic value to the grower from knowing the resistance (or susceptibility) status of weed populations to a range of herbicides is the ability to make a better-informed choice of cost-effective alternatives. However, there is industry concern that testing services are underutilised. In this project we addressed the following research questions:

- What are the perceived benefits, extent and reasons for growers and agronomist using herbicide resistance testing?
- Do growers and agronomists correctly assess the status of weed resistance

We used laboratory weed sample testing in combination with growers and agronomists' perceptions of the weed sample resistance strategy. We found that tests suggest that growers and agronomists are usually accurate in their assessment of resistant weed populations. However, it is common to underestimate susceptible weed populations and overestimate developing resistance, suggesting that testing offers value in confirming susceptibility to cost-effective herbicide options. In general, grower and agronomist assessment of resistance status is reasonably accurate, however there are instances where testing will lead to better informed weed management decisions.

The research findings were delivered to growers and agronomists in four workshops held across the wheatbelt and south coast. Growers valued the opportunity to hear directly from the researcher about how best to manage the risk of herbicide resistant weeds.

This research is supported by GRDC and UWA.

Development and characterisation of near isogenic lines (NILs) for herbicide (metribuzin) resistance in wheat (*Triticum aesitivum* L.) using transcriptomic and proteomic approaches

Project team: Rudra Bhattarai[1], Professor Guijun Yan[1] (project leader; guijun.yan@uwa.edu.au), Dr Hui Liu[1], Hackett Professor Kadambot Siddique[1]

Collaborating organisation: [1]UWA

Wheat is one of the most valuable crops in the world. It is the biggest agricultural commodity in Australia in terms of yield and trade. However, weed infestation is affecting crop production, which has been estimated to cost Australian agriculture around AUD $2.5 to 4.5 billion per annum. Therefore, controlling weeds using any means is necessary. Chemical-based weed control technique is one of the most effective methods. Among others, metribuzin is recommended as a most commonly used herbicide in dry-land farming systems to control a broad spectrum of weeds. However, narrow safety margin in wheat limits the wider use of metribuzin in wheat field. Therefore, the development of wheat varieties resistance to metribuzin is paramount.

The development of metribuzin resistance in wheat could occur through resistance gene identification and introduction. To introduce such resistance genes, overall gene characterisation is essential. Therefore, the primary aim of this study is to utilise the identified resistant germplasm in dissecting metribuzin resistance genetically through the development and characterisation of near isogenic lines (NILs).

Metribuzin resistance quantitative trait loci (QTL) have been successfully mapped in wheat by our group. However, QTL markers have limitations to be used directly for gene pyramiding, tagging and marker-assisted selection programs but they can be used in developing NILs. NILs are important in studying responsible genes affecting the phenotype. As genetic backgrounds in NILs are fixed apart from the target loci, the differences in phenotypes are due to the targeted gene(s).

Additionally, the successful development of NILs allows localising the genes controlling the trait accurately, enhancing the mapping resolution of complex quantitative traits into a Mendelian factors.

From 2020-2021, HIF (Heterogeneous Inbred Family) combined with a Fast Generation Cycling System (FGCS) and Marker Assisted Selection (MAS) method was used in recombinant inbreed lines (RILs) of Chun Mai 25 and Ritchie. A marker from QTLQsns.uwa.4A.2 was used to select the individual heterozygous line until F7 generation and contrasting homozygous lines in the F8 generation. Eighteen putative NIL pairs targeting the QTL Qsns.uwa.4A.2 were identified and were used for metribuzin assessment. Seven pairs were confirmed as true NILs and others were found to be recombinant types.

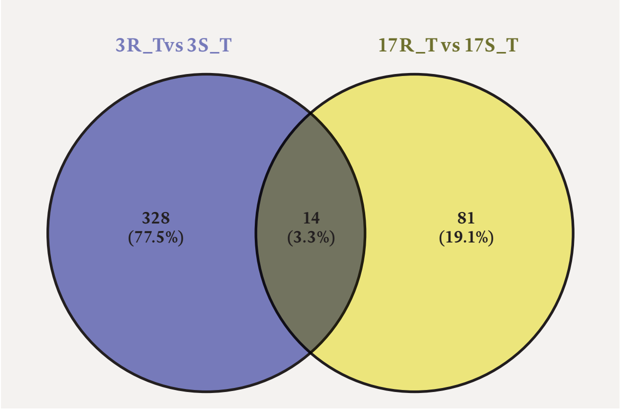
The resistant allele from the resistant isolines increased metribuzin resistance by 63–85 per cent (average 69 per cent) compared with the susceptible allele from the susceptible isolines. Thousand-grain weight (TGW) co-segregated with metribuzin resistance in confirmed NILs, signifying that closely linked genes control the two traits. The development, characterisation and validation of the NILs were summarised into a paper published in *Plants*.

This follow-up study is to characterise the confirmed NILs through transcriptomics and proteomics for the identification of genes responsible for metribuzin resistance. Therefore, two of the confirmed NIL pairs were used for RNA-sequencing. Through bio-informatical analysis, six upregulated genes and three downregulated genes were found overlapping between two NIL pairs in the QTLQsns.uwa.4A.2 region. Information from RNA-sequencing will also be utilised in identifying SNPs and Indel markers for marker assisted breeding of metribuzin resistance.

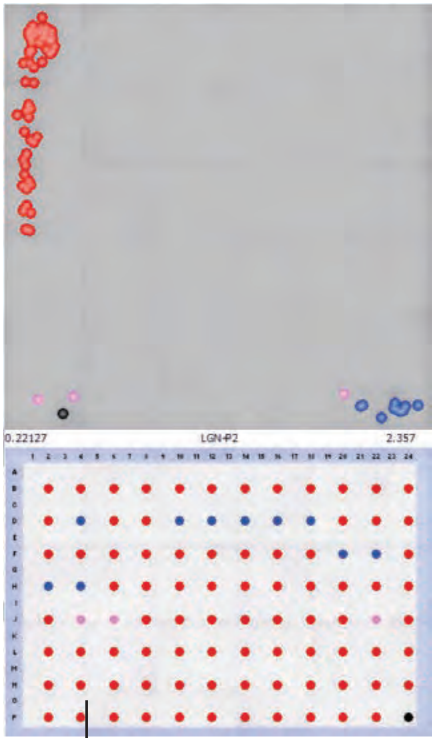
These two NIL pairs along with another one will also be used for peptide analysis to identify the differentially expressed proteins responsible for metribuzin resistance. This study is expected to generate interesting results for understanding metribuzin resistance in wheat.

This research is supported by the UWA RTPFI – RTP International Fees Offset, UPAIS University Postgraduate Award, and Global Innovation Linkages Program.

A contrasting NIL pair for RNA sampling. '17+' is the isoline with the alleles from Chuan Mai 25 (resistant) and '17-' is the isoline with alleles from Ritchie (susceptible). Fifteen-day-old wheat seedlings were sampled for RNA extraction.



Venn diagram showing differentially expressed genes (DEGs) based on mRNA sequence analysis.



A KASP marker screening result of diverse wheat genotypes for preharvest sprouting, drought and herbicide responses.

Interrogating wheat genome sequences for molecular marker-assisted breeding of Australian wheat (*Triticum aestivum* L.)

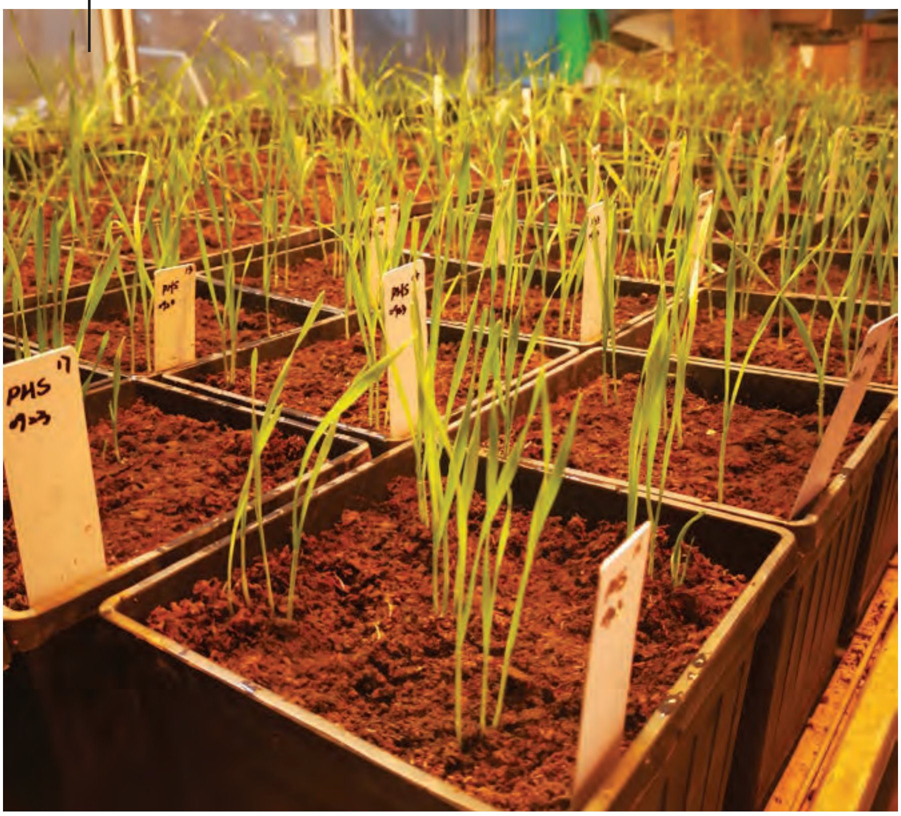
Project team: Professor Guijun Yan[1] (project leader; guijun.yan@uwa.edu.au), Dr Daniel Mullan[2], Dr Hui Liu[1], Professor Aimin Zhang[3], Professor Dongcheng Liu[3], Guannan Liu[1]

Collaborating organisations: [1]UWA; [2]InterGrain; [3]Hebei Agricultural University, China

Wheat (*Triticum aestivum* L.) is the most important crop grown in Australia. The large and complex genome of wheat makes it difficult for identification of functional markers for marker assisted breeding. Genome sequencing is a rapidly advancing area, which has a great potential in speeding up discovery of molecular markers or functional genes for molecular breeding. This PhD research project is to apply single nucleotide polymorphism (SNP) array and genotype by sequencing (GBS) technologies to study the genetic variations of representative wheat lines including domesticated cultivars and cross population progenies such as near isogenic lines (NILs) and recombinant inbred lines (RILs). Three agronomic traits: pre-harvest sprouting (PHS), drought and herbicide tolerance will be investigated. Phenotypes with extreme (best or worst) performances of the traits will be genotyped using array and sequencing technologies and genes or quantitative trait loci of interest will be identified based on the major polymorphisms between the extreme genotypes. DNA markers linked to genes of interest will be developed and validated on a wide range of wheat germplasm before implementation in breeding programs. It is expected that a number of functional markers for genes of breeding interest will be developed through this study, which can be cost-effectively applied to marker-assisted selection (MAS) in wheat breeding. The overall aim is to develop an efficient system for the identification of molecular markers for MAS in wheat which has a large polyploid genome.

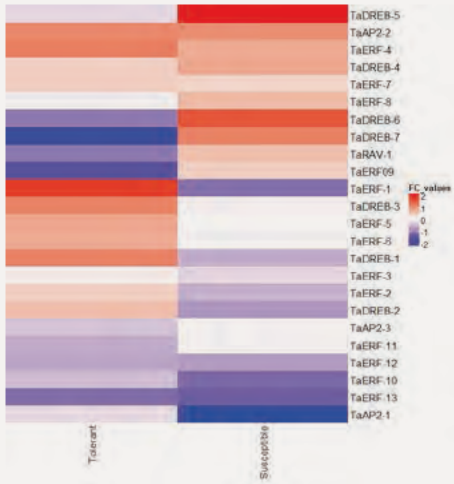
There are three major highlights in the 2021 research. Firstly, Putative functional markers have been finished for PHS tolerance experiment and drought tolerance experiment. Based on the literature and the materials phenotyped in our lab, four pairs of PHS tolerant/susceptible NILs and four pairs of drought tolerant/susceptible NILs were selected. All of them were grown in glasshouse conditions. Leaves at seedling stage were selected for DNA extraction, with each sample in duplicate. The quality and concentration of the DNA were tested by NanoDrop and Qubit. Secondly, validation of molecular markers for PHS tolerance experiment has been partially done. Thirdly, candidate DArT markers have been selected for the herbicide tolerance experiment using an F8 RIL population. These RILs were derived from the cross between Chunmai 25 (metribuzin tolerance) and Ritchie (metribuzin susceptible) and were grown in controlled temperature room.

This research is supported by RTP and the Global Innovation Linkages Program.



Phenotyping the diverse wheat genotypes under glasshouse conditions for pre-harvest sprouting, drought and herbicide responses.

The heatmap showing gene regulation pattern of 24 TaAP2/ERF genes in wheat genotypes. The intensity of colour shows the direction of gene regulation, where blue colour shows the downregulated genes, and the red colour shows upregulated genes.



Gene-based analysis of heat tolerance in bread wheat (*Triticum aestivum* L.) at seedling and reproductive stages

Project team: Manu Maya Magar[1], Professor Guijun Yan[1] (project leader; guijun.yan@uwa.edu.au), Dr Hui Liu[1]

Collaborating organisation: [1]UWA

Wheat (*Triticum aestivum* L.) is a major cereal in the world contributing a large proportion of human calorie and it also has great economic importance in Australia for domestic and international markets. As a winter crop, wheat production is highly affected by increasing temperature due to climate change. Therefore, development of heat resilient wheat genotype is a prime need, to cope with global food shortage.

Breeding for a polygenic trait like heat tolerance in hexaploid wheat is a serious challenge, which requires a clear understanding of heat tolerance mechanism of the plant. The expression of heat stress (HS) related traits involves activation of molecular networks of heat responsive genes by transcription factor (TF) genes (SINGH et al. 2019). Therefore, TF genes acts as a switch to regulate heat tolerance mechanism in wheat. To understand the role of TF genes in wheat, we aim to identify key TF genes responsive to HS, characterise them and analyse their expressions at seedling and reproductive stages in wheat genotypes which are phenotypically contrasting for heat tolerance.

In 2021, we have selected 24 TaAP2/ERF genes through rigorous bioinformatic analysis of TaAP2/ERF gene super-family in wheat genome. The wheat genotypes were morphologically identified as heat tolerant and heat susceptible at seedling stage. The RNA extracted from these wheat seedlings were used to synthesise the cDNA. The cDNA thus obtained were amplified with gene-linked markers in quantitative real-time polymerase chain reaction (RT-qPCR) with β-actin as housekeeping gene, to evaluate the gene expression under heat stress.

The gene expression values calculated by using $2^{-\Delta\Delta CT}$ method (Livak and Schmittgen 2001), measured the extent of gene expressed under heat stress. The fold change (FC) in gene expression was under HS over control for both tolerant and susceptible genotypes revealed the pattern of gene regulation. This demonstrated TaAP2/ERF genes are expressed differently in heat tolerant and susceptible genotypes under heat stress condition.

For reproductive stage experiment, four wheat genotypes grown in the glasshouse in completely randomised design were exposed to heat stress at 10 days post-anthesis. The measurement of physiological parameters and sampling was done after treatment in three time points.

The plants were measured for morphological parameters at physiological maturity, harvested and dried to take the biomass and yield related traits in each genotype.

In 2022, the morphological data measured for the reproductive stage plants will be analysed to evaluate their performance under heat stress. The molecular validation of these samples using qPCR with the TF genes highly expressed under heat stress at seedling stage will be conducted. The other two gene families will be analysed to validate their expression under heat stress in wheat genotypes.

In conclusion, genome-wide analysis and validation of TaAP2/ERF TF genes will provide a better understanding on how the TF genes regulate heat tolerance mechanism in wheat. This will provide a strong basis for molecular breeding of wheat for heat tolerance.

This research is supported by the UIFS, UPA, and Global Innovation Linkages Program.

PhD candidate Manu Maya Magar with wheat genotypes grown in glasshouse for heat treatment at reproductive stage.

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]

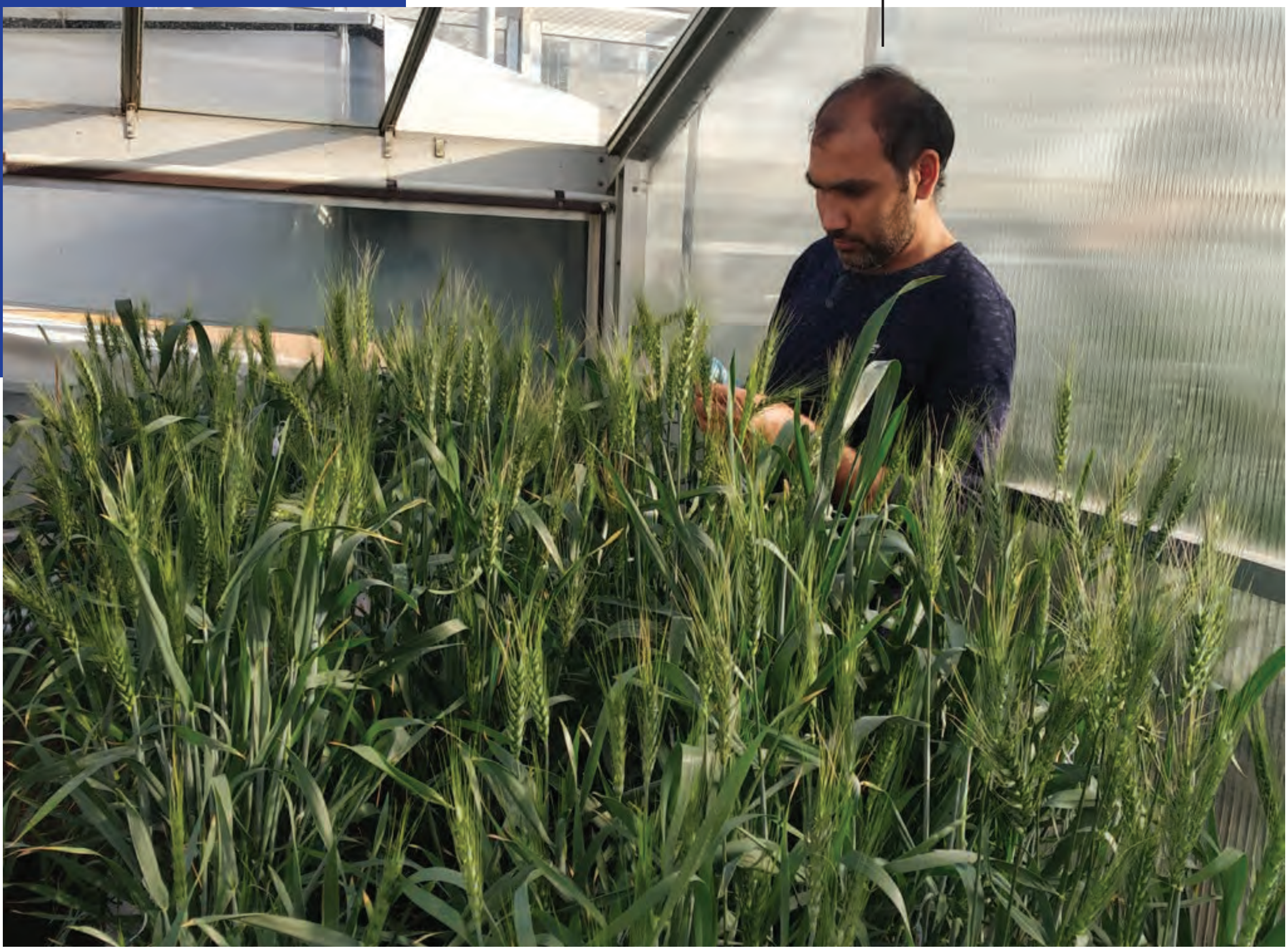
Collaborating organisation: [1]UWA

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 14-18 days before anthesis. In 2021, we published our results which showed that heat stress during meiosis in the main stem reduced final seed yield as a result of fewer and smaller seeds, especially in the terminal ends of the spike. We used conditions that mimicked heat waves during meiosis (early booting stage) in the field, and we supplied ample water to avoid drought stress.

We found significant genetic variation among 30 wheat genotypes for grain yield and grain number in the main stem following heat stress and identified potential heat stress tolerant and sensitive cultivars.

The most heat-tolerant and heat-sensitive genotypes were intercrossed in 2021 to develop biparental mapping populations, which we will use in future experiments to discover genomic regions (QTLs) that govern heat stress tolerance. DNA samples from F2 plants were submitted for whole-genome marker analysis, and the plants were submitted to heat stress which will be the basis of QTL mapping and validation in the F3 generation.

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



PhD student Mukesh Choudhary in a UWA glasshouse.

Identification of candidate genes for root traits using genotype–phenotype association analysis of near-isogenic lines in hexaploid wheat (*Triticum aestivum* L.)

Project team: Tanushree Halder[1,2], Dr Hui Liu[1], Dr Yinglong Chen[1], Professor Guijun Yan[1], Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au)

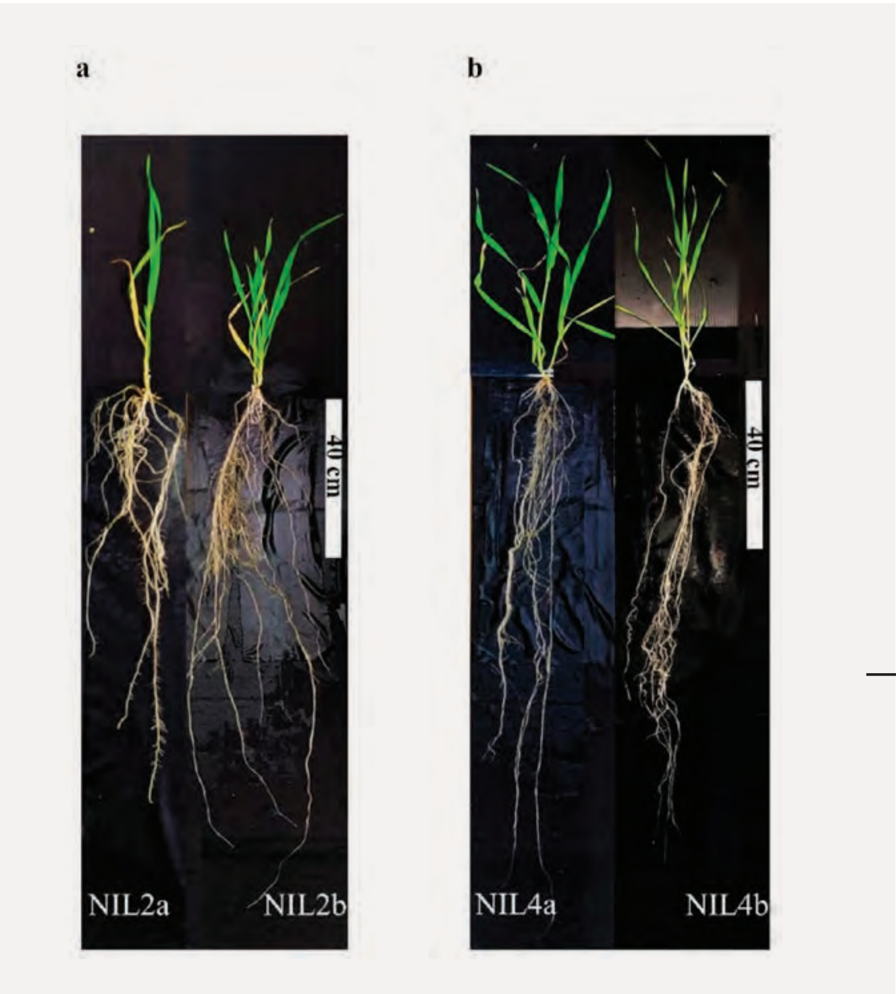
Collaborating organisations: [1]UWA; [2]Sher-e-Bangla Agricultural University, Bangladesh

Global wheat (*Triticum aestivum* L.) production is constrained by different biotic and abiotic stresses, which are increasing with climate change. An improved root system is essential for adaptability and sustainable wheat production.

In this study, 10 pairs of near-isogenic lines (NILs) – targeting four genomic regions (GRs) on chromosome arms 4BS, 4BL, 4AS, and 7AL of hexaploid wheat – were used to phenotype root traits in a semi-hydroponic system. Seven of the 10 NIL pairs significantly differed between their isolines for 11 root traits. The NIL pairs targeting qDSI.4B.1 GR varied the most, followed by the NIL pair targeting qDT.4A.1 and QHtscc.ksu-7A GRs. For pairs 5-7 targeting qDT.4A.1 GR, pair 6 significantly differed in the most root traits. Of the four NIL pairs targeting qDSI.4B.1 GR, pairs 2 and 4 significantly differed in 3 and 4 root traits, respectively. Pairs 9 and 10 targeting QHtscc.ksu-7A GR significantly differed in 1 and 4 root traits, respectively.

This study characterised, for the first time, that these GRs control root traits in wheat, and identified candidate genes, although the candidate genes will need further confirmation and validation for marker-assisted wheat breeding.

This research is supported by UWA, the Australian Government RTP scholarships, and Global Innovation Linkages Program.



Contrasting rooting depth of two pairs of wheat near-isogenic lines (NILs) at 42 days after transplanting in a semi-hydroponic system in a glasshouse.

Comparisons among four different upscaling strategies for cultivar genetic parameters in rainfed spring wheat phenology simulations with the DSSAT-CERES-Wheat model

Project team: Dr Shang Chen[2], Liang He[3], Dr Yinxuan Cao[2], Professor Runhong Wang[2], Lianhai Wu[4], Dr Zhao Wang[5], Adjunct Associate Professor Yufeng Zou[1,2], Hackett Professor Kadambot Siddique[1], Professor Wei Xiong[6], Dr Manshuang Liu[2], Dr Hao Feng[2], Professor Qiang Yu[2], Dr Xiaoming Wang[2], Dr Jianqiang He[2] (project leader; jianqiang_he@nwsuaf.edu.cn)

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]National Meteorological Center, China; [4]Rothamsted Research, UK; [5]Shaanxi Agricultural Remote Sensing and Economic Crop Meteorological Service Center, China; [6]Henan Agricultural University, China

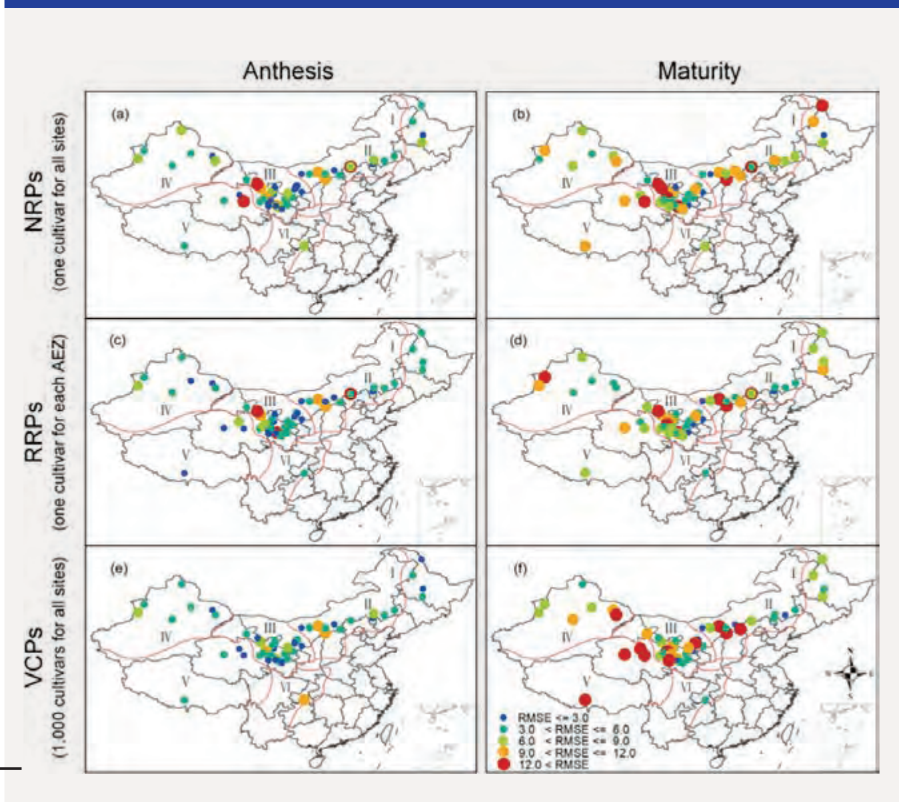
Cropping system models are widely used to assess the impacts of and adaptation practices to climate change on agricultural production. However, crop growth simulations at large scales have often lacked consideration of variation in crop cultivars, which were represented by different sets of genetic coefficients in crops models.

In this study, taking the phenology of spring wheat (*Triticum aestivum* L.) as an example, we compared four different strategies for upscaling genetic parameters in phenology simulations at large scales with two experimental datasets. The first dataset was from field experiments comprising 40 different spring wheat cultivars at Altay (2014) and Yangling (2015–2017) station; the second dataset was historical (2010–2014) observed phenology records from 57 national agro-meteorological observation stations in China.

The four strategies were the representative cultivar estimated at a single site (SSPs), the representative cultivar estimated at the 57 sites (NRPs), the various representative cultivars estimated at different agro-ecological zones (RRPs), and the virtual cultivars generated from the posterior distributions (VCPs). The posterior distributions aforesaid were established based on the calibrated parameter values of the 40 different spring wheat cultivars planted in Yangling. Then, 1000 sets of VCPs were randomly sampled from the posterior distributions. The results indicated that both the SSPs and NRPs strategy obtained large errors and uncertainties in spring wheat phenology simulations in China since only one representative cultivar was used. The RRPs strategy achieved the second high and the highest accuracy in anthesis and maturity data simulations.

The VCPs strategy obtained the highest accuracy in anthesis simulation but relative larger errors in maturity simulation. The VCPs strategy can be directly used in large-scale crop growth simulations without tedious process of calibration. Hence, this strategy is recommended in areas where observations are scarce and for model users who are not good at model parameter estimation.

This research is supported by the Natural Science Foundation of China, Key Research and Development Program of Shaanxi, 111 Project of China, and NERC Newton Fund of UK.



Spatial distributions of the root mean square errors (RMSEs) between the observed and estimated anthesis (a, c, e) and maturity (b, d, f) dates with three upscaling strategies of cultivar genetic parameters at the 57 agro-meteorological observation sites of China in 2010–2014.

Revealing heat stress tolerance mechanisms in bread wheat (*Triticum aestivum* L.) using proteomics approaches

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

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

This research project aims to unravel heat stress tolerance in bread wheat (Triticum aestivum L.) by investigating changes in leaf and spike proteomes.

Crop improvement is an amalgamation of various knowledge bases for improving plant development and yield potential. Molecular biology, with its modern tools and techniques has the potential to provide specific targets for crop improvement. Significant research is being carried out on abiotic stress tolerance to identify molecular targets for improvement. These molecular targets together with the modern tools, will provide a faster and more reliable approach for improving crop yield potential.

Temperature is a major environmental stress that impacts plant development and yield. Heat stress limits the yield potential of field crops by accelerating phenology and reducing the seed filling duration.

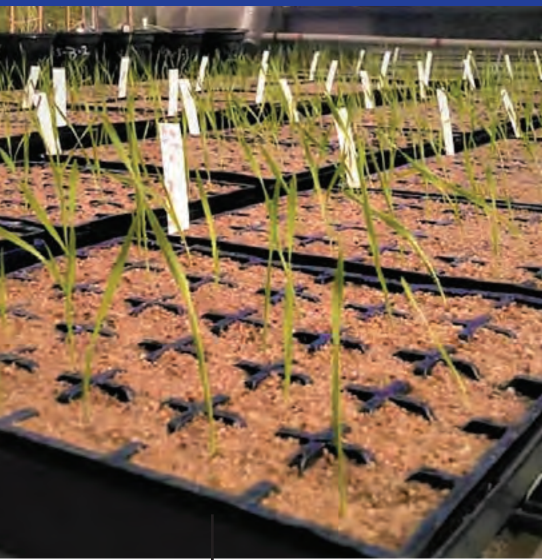
Heat stress responses can be linked to many regulatory and functional genes, with plants often engaging in early responses to external stresses in the form of altered calcium flux and phosphorylation, to activate multiple effectors and thus, a large cascade of proteins operating downstream to the stress receptors and sensors. A comprehensive understanding of the molecular impacts of terminal heat stress is critical for identifying key molecular traits/targets to improve heat stress tolerance. This knowledge will be crucial in the race against time to feed the ever-increasing global population.

The expected outcomes are as follows: Quantitative comparison of physiological, morphological and yield related traits between the 4 varieties (Tolerant: RAJ3765, HD2932 and Susceptible: HD2733, HD 2329) under heat stress/increased temperatures during anthesis. Identification of cell-surface and soluble proteins along with the downstream pathways involved in tolerance to heat stress/increased temperatures in wheat.

This research is supported by UWA.

Recording leaf gas exchange using infrared gas analyser.

Agyeya Pratap during his first stress trial recording leaf, spike and canopy temperature using infrared temperature sensor at IARI.



Phenotyping the diverse wheat genotypes for phytotoxicity following metribuzin application.

Genome wide association study to identify candidate genes for metribuzin tolerance in wheat (*Triticum aestivum* L.)

Project team: Benjamin Kurya[1], Dr Sultan Mia[1,2], Professor Guijun Yan[1] (project leader; guijun.yan@uwa.edu.au), Dr Helen Liu[1]

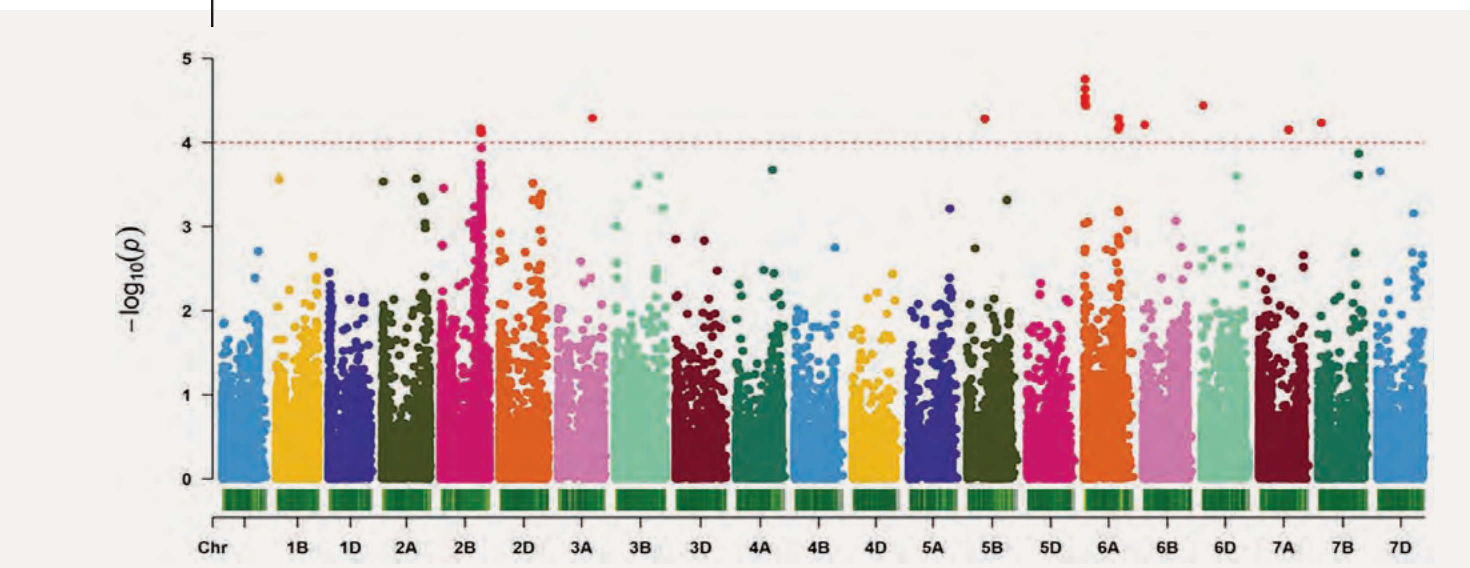
Collaborating organisations: [1]UWA; [2]DPIRD

Use of pre-emergent herbicides, such as metribuzin, is an integral part of no-till dryland farming systems in Australia. However, metribuzin can cause phytotoxicity, especially in susceptible crop genotypes. Understanding the genetics of metribuzin tolerance in wheat is vital for developing tolerant cultivars to improve wheat productivity. We conducted Genome-wide Association Studies (GWAS) on a diverse collection of wheat genotypes utilizing wheat 90K SNP array-based markers. Genotypes were sprayed with a metribuzin dose of 400 grams active ingredient (g. a.i.) ha-1 as pre-emergent in a specialised spraying cabinet and transferred to the glasshouse, where the tolerance level of the genotypes was assessed by measuring the relative reduction in chlorophyll content of the leaves.

The reduction in chlorophyll content of the treated plants compared to the control was regarded as the phytotoxic effects of metribuzin. GWAS analysis following a mixed linear model revealed 19 significant marker-trait associations (MTAs). Candidate genes identified within ±2Mb genomic regions of significant SNPs include TraesCS6A01G028800, TraesCS6A02G353700, TraesCS6A01G326200, TraesCS7A02G331000, and TraesCS2B01G465200, which have annotations related to herbicide tolerance in wheat. These genes were reported to be involved in pathways including cytochrome P450 and ATP Binding Cassette (ABC) superfamilies. Sufficient polymorphism was detected on two SSR markers (wms193 and barc1036) that can significantly differentiate between the susceptible and tolerant alleles suggesting that these markers can be used for marker-assisted selection (MAS) in metribuzin studies and wheat breeding programs.

This research is supported by the Australian Award scholarship and Global Innovation Linkages Program.

Manhattan plot representing associations between chlorophyll content index and SNP data.



The reference genome of rye closes the gap in the genome research in *Triticeae* and sheds new light into hybrid breeding in cereals

Project team: Dr Joanna Melonek[1,2] (project leader; joanna.melonek@uwa.edu.au), Professor Ian Small[1,2], Professor Nils Stein[3,4], Dr M Timothy Rabanus-Wallace[4], Dr Bernd Hackauf[5], Dr Viktor Korzun[6]

Collaborating organisations: [1]UWA; [2]ARC Centre of Excellence in Plant Energy Biology; [3]The Leibniz Institute of Plant Genetics and Crop Plant Research; [4]Center for Integrated Breeding Research, University of Göttingen, Germany; [5]Julius Kühn-Institut, Federal Research Centre for Cultivated Plants, Germany; [6]KWS SAAT SE & Co. KGaAa, Germany

In 2021, the reference genome sequences of two rye varieties 'Lo7' and 'Weining' were published (Rabanus-Wallace et al. 2021; Li et al. 2021). This extraordinary achievement closed the gap in the genome research in the Triticeae tribe and opened the way for genome-based breeding for crop improvement.

Rye (*Secale cereale* L.) is a diploid species that is closely related to bread wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). Rye shows exceptional frost tolerance and outyields wheat and barley on poor and medium soils. The published genome sequences will be extremely useful in comparative and functional studies as well as genome-based breeding approaches in rye, and also in its close relatives wheat and barley. For example, rye is an excellent donor of genes conferring resistance to pathogens and many resistance genes have been already transferred from rye to wheat by targeted breeding.

All commercial rye varieties are hybrids. Despite the great importance of hybrid breeding in rye, the genetic components of fertility restoration used to control self-pollination during the hybrid breeding process remain largely unknown. Dr Joanna Melonek and Professor Ian Small from the ARC Centre of Excellence in Plant Energy Biology in the School of Molecular Sciences, in collaboration with Professor Nils Stein and Dr M Timothy Rabanus-Wallace from the Leibniz Institute of Plant Genetics and Crop Plant Research (IPK-Gatersleben), Germany, contributed to the study through analysis of a group of genes known as restorer-of-fertility like (RFL) (Rabanus-Wallace et al. 2021). RFL genes have application to hybrid breeding in cereals as they are used to restore fertility of plants showing cytoplasmic male sterility (CMS), a trait applied to block self-pollination of parent lines during the hybrid cross.

The analysis of the RFL family in the 'Lo7' genome revealed an exceptionally high number of RFL genes in the rye genome compared to another diploid cereal barley or *Arabidopsis thaliana* (46 RFL genes in rye compared to 22 in barley or 24 in *A. thaliana*). Surprisingly, the *Rfp3* locus, which is currently used in hybrid rye breeding based on Pampa cytoplasm, was found to encode a factor from a different family of proteins known as mitochondrial transcription-termination factors (mTERF). Genome-wide characterisation of the mTERF gene family in the rye genome has shown, as for the RFL family, a relatively high number of mTERF genes in the genome (131 mTERFs in rye compared to 80 in barley or 35 in *A. thaliana*).

The reasons for the higher number of RFL and mTERF genes in the rye genome remain unclear. One of the proposed explanations pointed at the unusual reproductive strategy of rye (reviewed in Melonek et al. 2021). The species is the only small-grain cereal that exhibits self-incompatibility and high level of outcrossing. Future studies are needed to explain the reasons behind the high number of mTERF and RFL genes and how they contribute to fertility restoration of CMS plants. These insights will be directly applied to hybrid breeding in rye and will be transferrable to barley and wheat.

This research is supported by ARC LP200100547, Groupe Limagrain and the ARC Centre of Excellence in Plant Energy Biology.

Rye flowers.
A: Anthers,
B: Stigmas,
C: Sterile Pampa CMS.
Modified from Melonek et al 2021.

Professor Ian Small and Dr Joanna Melonek in the ARC Centre of Excellence in Plant Energy Biology laboratory.

Zeolite increases grain yield and potassium balance in paddy fields

Project team: Dr Yinghao Li[2], Dr Guimin Xia[2], Dr Qi Wu[2], Wei Chen[3], Wenhua Lin[4], Zhongxiao Zhang[4], Dr Yinglong Chen[1], Dr Taotao Chen[2] (project leader; taotao-chen@syau.edu.cn), Hackett Professor Kadambot Siddique[1], Professor Daocai Chi[2]

Collaborating organisations: [1]UWA; [2]Shenyang Agricultural University, China; [3]Water Conservancy and Hydropower Science Research Institute of Liaoning Province, China; [4]Water Affairs Service Center of Donggang, China

Most paddy fields in China are potassium (K) insufficient, while soil inorganic amendments such as zeolite are good strategies to increase soil K content. There is limited information on the interactive effects of zeolite and K applications on rice (*Oryza sativa* L.) productivity, apparent K balance, and soil K balance.

This two-year field study using a split-plot design with three replicates investigated the effects of zeolite and K applications on grain yield, soil available K dynamics, apparent K balance, and soil K balance in a paddy rice system. The main plots were three zeolite application rates (0, 5, and 10 t ha–1; Z0, Z5, and Z10). Within each main plot were subplots subjected to three K application rates (0, 30, and 60 kg ha–1; K0, K30, and K60). Zeolite was only applied in the first year while K was applied in both years. Results revealed that zeolite and K application, alone or in combination, significantly increased rice grain yield and economic benefit (based on resource inputs and grain value).

In both years, the combination of 5 t ha–1 zeolite with 30kg ha–1 K fertiliser (i.e., Z5K30) increased grain yield by up to 6.4 per cent and economic benefit by up to 6.6 per cent, relative to the most commonly used practice (i.e., Z0K60). With 5 and 10 t ha–1 zeolite amended, the highest K application rate (K60) did not further increase grain yield, but it decreased economic benefit, relative to the lower K application rate (K30). Zeolite and K application, alone or in combination, significantly increased topsoil (0–30 cm) average available K content, post-harvest aboveground K uptake, and apparent K balance in the paddy rice system. Zeolite and K application alone significantly increased soil K balance.

The results of this study demonstrated that zeolite amendments increased topsoil available K, enhanced rice K uptake, alleviated negative K balance, and improved productivity and agricultural profitability of paddy cultivation. The recommended treatment Z5K30 is suitable for rice cultivation due to its higher economic and environmental benefit as compared with the commonly used farmer practices.

This research is supported by UWA, the National Nature Science Foundation of China, Leading Talents of Liaoning Revitalization Talents Program, Provincial Foreign Training Projects, Provincial Nature Science Foundation of Liaoning, Distinguished Young Talents Foundation, and China Scholarship Council.

Rice (*Oryza sativa* L.) growing in a paddy field.

The project searches for traits conferring tolerance to abiotic stress among the wild rice relatives. Here is a rare example of Oryza longistaminata flowering in our glasshouse facility at UCPH, Denmark.

Climate-smart African rice

Project team: Adjunct Professor Ole Pedersen[1,2] (project leader; opedersen@bio.ku.dk)

Collaborating organisations: [1]UWA; [2]University of Copenhagen, Denmark; Sokoine University of Agriculture, Tanzania; International Rice Research Institute, the Philippines

This project aims at identifying novel genes or QTLs involved in flood or salinity tolerance to breed climate-resilient rice cultivars for East Africa. The project is using African rice and wild rice relatives to uncover trait capacities for flood or salinity tolerance and aims at an output of 1-2 high-yielding rice cultivars to help sustaining rice production under abiotic stress. The project is a collaboration between Sokoine University of Agriculture, the International Rice Research Institute and the University of Copenhagen.

The research team have gathered leading scientists in the field with the aim of delivering modern rice cultivars to farmers in Africa in order to ease the calamities of the ongoing climate changes. This project will also result in novel scientific discoveries and thereby strengthen research in Africa, Denmark and Australia.

Our work has suffered from the travel restrictions that were put in place only two months after commencing the project, but we soon expect to receive staff from Sokoine University of Agriculture for training in key physiological measurements here in Copenhagen. A brand new screenhouse is being constructed at SUA and about 300 genotypes of rice are now being screened for tolerance to flooding and salinity.

IRRI has recently established a hub in East Africa lead by Abdelbagi Ismail and team, and IRRI has been instrumental in providing knowhow and support to our key partners at SUA. At SUA, new PhD and Masters students have been enrolled and they have all defended their proposals and are now working in the field or screenhouse areas with phenotyping. At UCPH, several BSc and MSc students have already graduated, and two PhD students funded by China Scholarship Council are currently also working on the project.

This research is supported by the Danish International Development Agency.

Seeds from Africa Rice and the International Rice Research Institute are being multiplied in the experimental fields of Sokoine University of Agriculture, Morogoro, Tanzania.

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], Kiran Veluru[1], Dr Rajneet Uppal[2], Dr Suman Rakshit[3], Matt Davey[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.

The 2020 trial data from the UWA Shenton Park Field Station revealed several genotypes with good tolerance to heat stress or capacity to recover after heat stress. These putative heat tolerant genotypes were re-evaluated in 2021 along with some new genotypes (total 210) under the same heat stress regime. The heat-tolerant genotypes were also sent to Chile for seed increase and will be further validated in national field trials at 4 different sites in 2022.

All genotypes phenotyped for heat tolerance in 2020 and 2021 at UWA were subjected to whole genome SNP-based genomic analysis. New genetic diversity was found among heat-tolerant and sensitive genotypes including resynthesised *Brassica napus* lines with introgression of DNA from related species. These genotypes are genetically distant to commercial canola cultivars.

In 2020 and 2021, 12 putative heat tolerant or sensitive genotypes were assessed for 2 years in the field in portable heat chambers at NSW DPI (Wagga Wagga). The results suggested that heat stress at early flowering is more stressful to canola plants than heat stress at 50 per cent flowering in terms of the seed number per pod, harvest index as well as plot yield. These results were consistent with our results from controlled environment facilities at UWA, indicating that the protocol we established based on controlled environment facilities at UWA was efficiently transferred to the portable heat chambers in the field.

Data from irrigated field trials in 2020 at Narrabri and Leeton in NSW were analysed to assess field heat tolerance in 30 genotypes sown at different times, where late sowings were expected to experience heat stress at flowering. Several genotypes performed well under heat stress conditions in 2020, and 24 genotypes were selected for further validation in field trials at four locations across Australia in 2021: Dongara in WA, Kerang in Victoria, Leeton and Condobolin in NSW. The seed yield and relevant data from all four sites were collected for analysis.

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 GRDC, UWA and NSW DPI.

Portable heat chambers at Wagga Wagga build a great bridge between controlled environment facility at UWA and field trials. Image credit: Dr Rajneet Uppal from NSW DPI.

Dr Sheng Chen introducing the progress of the GRDC-funded canola heat tolerance project at the UWA Shenton Park Field Station Open Day in 2021.

Female reproductive organs of *Brassica napus* are more sensitive than male to transient heat stress

Project team: Dr Sheng Chen[1] (project leader; sheng.chen@uwa.edu.au), Dr Renu Saradadevi[1], Professor Miriam Vidotti[2], Dr Roberto Fritsche-Neto[2], Dr Jose Crossa[3], Hackett Professor Kadambot Siddique[1], Professor Wallace Cowling[1]

Collaborating organisations: [1]UWA; [2]University of São Paulo, Brazil; [3]CIMMYT, Mexico

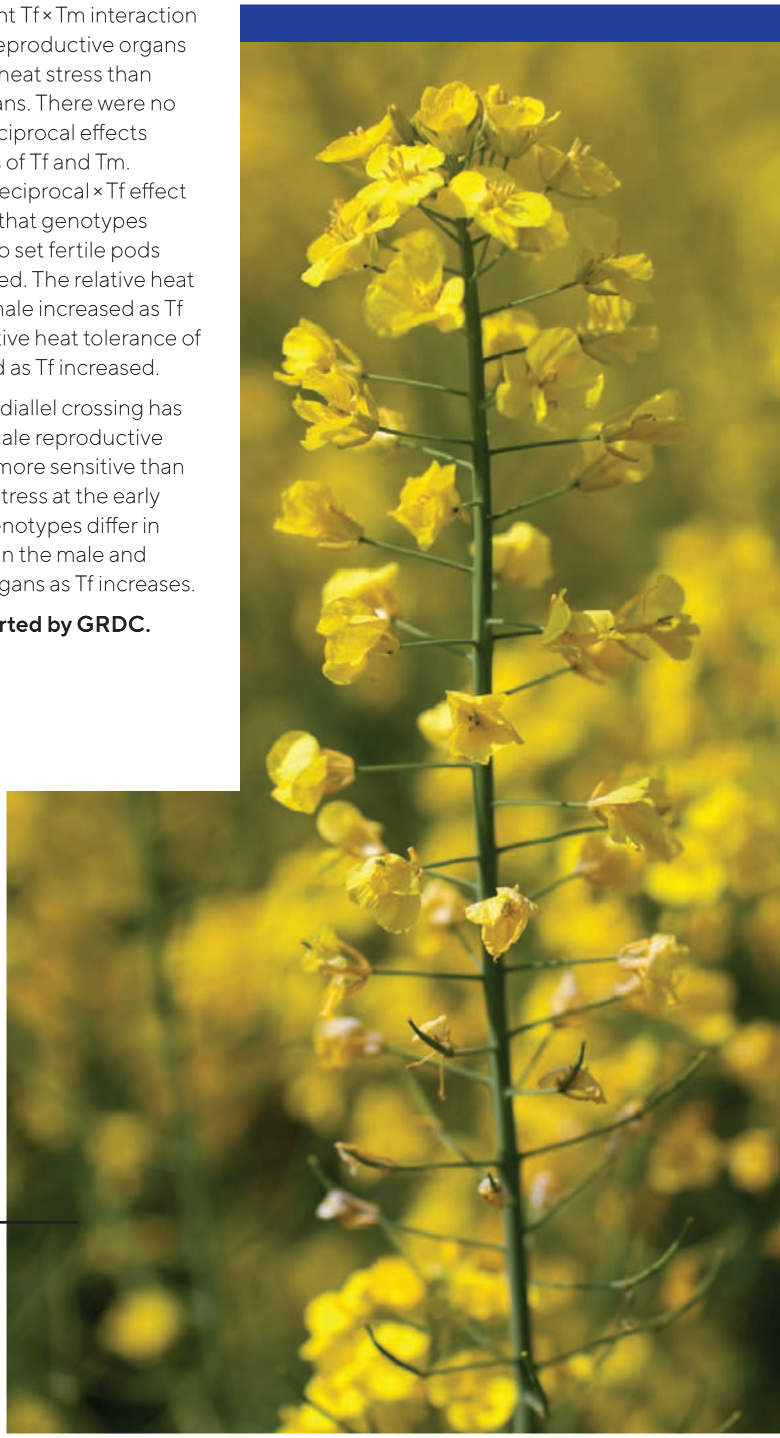
This research was published in 2021 and is part of the 'Improving canola heat tolerance – A coordinated multidisciplinary approach' project.

Oilseed rape (*Brassica napus* L.) is sensitive to heat stress during the reproductive stage, but it is not clear whether the male and female reproductive organs differ in their sensitivity to heat stress.

In this study, full diallel crossing experiments were conducted among four genotypes of *B. napus* under control, moderate and high heat stress conditions for five days immediately before and two days after crossing. General combining ability (GCA), specific combining ability (SCA) and reciprocal effects were analysed to evaluate the genetic basis of heat stress tolerance in male and female reproductive organs. High female temperature (Tf) and high male temperature (Tm) reduced the number of fertile pods and seeds set per floret, and the significant Tf × Tm interaction indicated that female reproductive organs were more sensitive to heat stress than male reproductive organs. There were no overall GCA, SCA or reciprocal effects across all combinations of Tf and Tm. However, a significant reciprocal × Tf effect was found, suggesting that genotypes differed in their ability to set fertile pods and seeds as Tf increased. The relative heat tolerance of G1 as a female increased as Tf increased, and the relative heat tolerance of G2 as a male decreased as Tf increased.

In summary, reciprocal diallel crossing has demonstrated that female reproductive organs of *B. napus* are more sensitive than male to transient heat stress at the early flowering stage, and genotypes differ in relative heat tolerance in the male and female reproductive organs as Tf increases.

This research is supported by GRDC.



Oilseed rape is a bright-yellow flowering member of the family Brassicaceae.

Nitric oxide secures reproductive efficiency in heat-stressed lentil (*Lens culinaris* Medik.) plants by enhancing the photosynthetic ability to improve yield traits

Project team: Hackett Professor Kadambot Siddique[1], Professor Harsh Nayyar[2] (project leader; nayarbot@pu.ac.in), Dr Kumari Sita[2], Akanksha Sehgal[2], Anjali Bhardwaj[2], Kalpna Bhandari[2], Dr Shiv Kumar[3], Dr P. Vara Prasad[4], Dr Uday Jha[5], Dr Akanksha Sehgal[6]

Collaborating organisations: [1]UWA; [2]Panjab University, India; [3]ICARDA, Morocco; [4]Kansas State University, USA; [5]Indian Institute of Pulses Research, India; [6]Mississippi State University, USA

Rising temperatures, globally and locally, would be detrimental for cool and summer-season food legumes, such as lentil (*Lens culinaris* Medik.). Lentil is highly sensitive to supra-optimal temperatures (>30 °C), particularly during reproductive growth, resulting in flower and pod losses. Thus, suitable strategies are needed to introduce heat tolerance in this legume.

In this project, the researchers evaluated the efficacy of nitric oxide (NO) – applied as foliar treatment of 1 mM sodium nitroprusside (SNP), twice (one day before final exposure to high temperature, and again five days later) – on heat-stressed (32/20 °C) lentil genotypes, differing in heat sensitivity. As a result of heat stress, endogenous NO increased significantly in heat-tolerant genotypes (46-62 per cent in leaves and 66-68 per cent in anthers, relative to the respective controls), while it decreased in heat-sensitive (HS) genotypes (27-30 per cent in leaves and 28-33 per cent in anthers, relative to the respective controls).

Foliar supplementation with SNP markedly increased endogenous NO in leaves and anthers of both the control and heat-treated plants. Heat stress significantly accelerated phenology, damaged membranes, chlorophyll, chlorophyll fluorescence, cellular viability, and decreased leaf water status, carbon fixing and assimilating ability, less so in plants treated with SNP. Heat stress plus SNP significantly improved carbon fixation (as RuBisCo activity) and assimilation ability, (as sucrose concentration (in leaves and anthers), sucrose synthase and vacuolar acid invertase activity, reducing sugars), as well as osmolyte accumulation (proline and glycine betaine) in leaves and anthers. Moreover, SNP-treated plants had significantly less oxidative damage – measured as malondialdehyde and hydrogen peroxide concentrations – in leaves and anthers, relative to the respective control.

Reproductive function – assessed as pollen grain germination and viability, stigma receptivity, and ovular viability – decreased markedly in plants exposed to heat stress alone, more so in HS genotypes, but increased significantly with SNP treatment as a consequence of improved leaf and anther function, to significantly increase the pod and seed numbers in heat-stressed lentil plants, relative to heat-stress alone.

This research is supported by ICARDA, Morocco.

Lentil (*Lens culinaris* Medik.) plants growing in a field.

Critical external P requirements for chickpea and wheat supplied with struvite

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

Collaborating organisations: [1]UWA; WA Department of Agriculture, Water and the Environment; Water Corporation, Perth; The ARC Training Centre for Transformation of Australia's Biosolids Resource; The AW Howard Memorial Trust

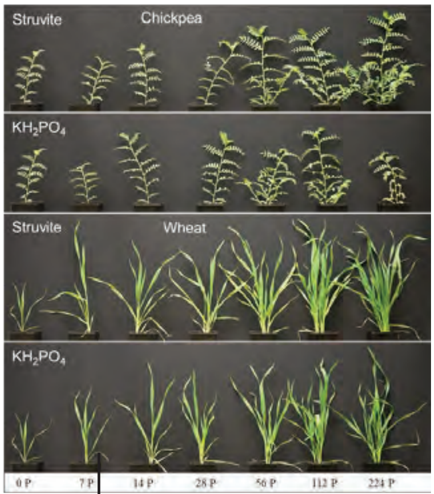
Phosphorus (P) is an essential nutrient for plants. The main source of P fertiliser is phosphate rock reserves, are non-renewable and will be exhausted in the next few centuries due to increasing P demand. Therefore, sustainable P sources are urgently needed to increase food production in the face of an increasing global human population. One viable solution is to recycle P from current waste streams in the food production and consumption system.

Struvite is a crystal of magnesium ammonium phosphate, derived from human wastewater via precipitation. As struvite releases nutrients slowly thus providing fertilisation for longer period than commercially available soluble P fertilisers, it may minimise nutrient leaching and eutrophication.

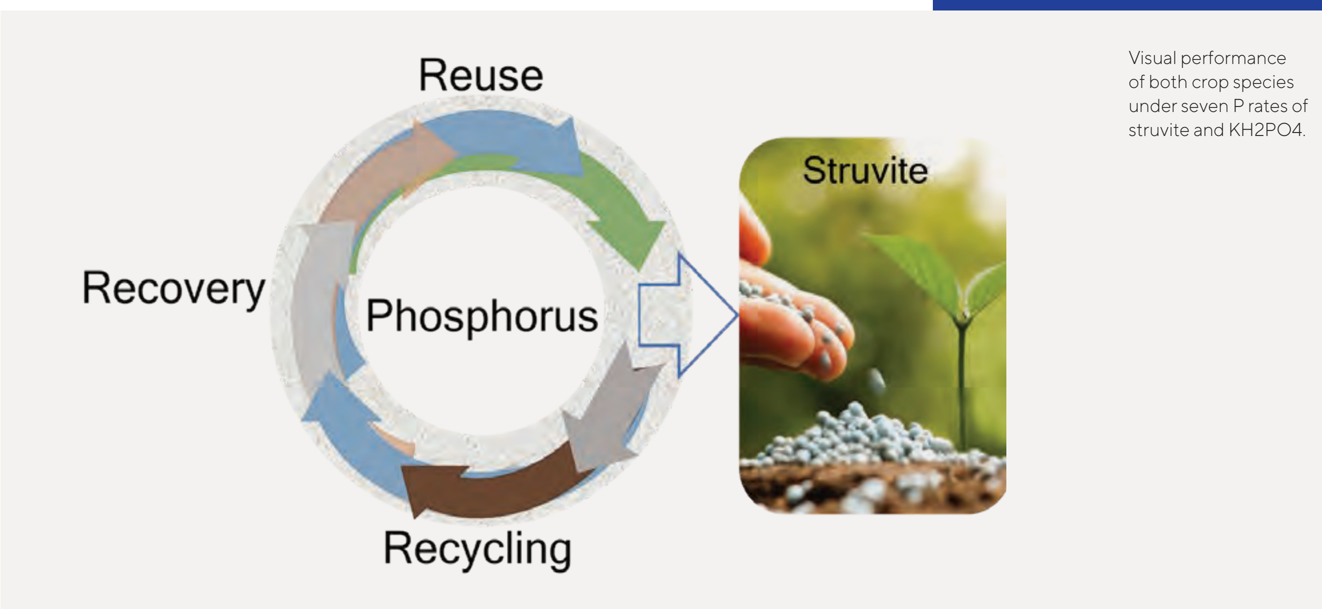
The main objective of Manish Sharma's PhD was to evaluate the agricultural potential of struvite as a sustainable P fertiliser source. Mr Sharma's first experiment aimed to determine the critical external P requirement for chickpea (*Cicer arietinum* L.) and wheat (*Triticum aestivum* L.) supplied with struvite. Chickpea cv. Neelam and wheat cv. Scepter plants were grown in a temperature-controlled glasshouse and supplied with two P sources (struvite and KH_2PO_4) at seven P rates (0, 7, 14, 28, 56, 112, 224 mg P kg^{-1} dry soil). Plants were harvested nearly eight weeks after sowing. Plant growth increased with increasing P rates in a similar manner for slowly soluble (struvite) and readily soluble (KH_2PO_4) P sources. Struvite–fertilised plants acquired either higher or similar nutrients (P, magnesium and nitrogen) compared to KH_2PO_4 fertilised plants. Wheat recovered more P than chickpea under both fertilisers, and struvite-fertilised wheat recovered significantly more P than KH_2PO_4-fertilised wheat.

The results suggest that struvite has great potential to be used as an alternative P fertiliser given its comparable or superior effects to readily soluble KH_2PO_4.

This research is supported by the WA Department of Agriculture, Water and the Environment, UWA, and The AW Howard Memorial Trust.



Recycling of phosphorus as struvite.



Visual performance of both crop species under seven P rates of struvite and KH2PO4.

Novel genes and genetic loci associated with root morphological traits, phosphorus-acquisition efficiency and phosphorus-use efficiency in chickpea

Project team: Associate Professor Mahendar Thudi[2,4], Dr Yinglong Chen[1], Dr Jiayin Pang[1], Professor Manish Roorkiwal[3], Dr Danamma Kalavikatte[2], Dr Prasad Bajaj[2], Dr Annapurna Chitikineni[2], Professor Megan Ryan[1], Emeritus Professor Hans Lambers[1], Hackett Professor Kadambot Siddique[1], Professor Rajeev Varshney[1,2,3] (project leader; rajeev.varshney@murdoch.edu.au)

Collaborating organisations: [1]UWA; [2]ICRISAT; [3]Murdoch University; [4]Shandong Academy of Agricultural Sciences, China

This project used genome mapping on chickpea root traits to improve the efficiency of phosphorus acquisition and use. Chickpea is the second most important pulse crop grown worldwide, and the second largest pulse crop in Australia – producing more than 500 thousand tonnes annually. Phosphorus is an essential nutrient for crop production, and deficiencies in phosphorus often lead to reduced crop yield.

Sustaining food production for a growing world population requires a large input of phosphorous fertilisers, which are manufactured from non-renewable resources that are expected to diminish dramatically in the coming decades. Approximately 29 per cent of crops across the world are now deficient in phosphorus.

UWA and ICRISAT researchers identified genes and loci for chickpea root architecture and root traits that were associated with phosphorus acquisition and use efficiencies. The research team used three statistical models to identify more than 100 marker-trait associations. Of these, the researchers identified one single genetic variation that they associated with phosphorous uptake and use efficiency. They also identified genes related to physiological phosphorus-use efficiency, specific root length, and manganese concentration in mature leaves.

This is the world's first study that reported genomic regions associated with the above important traits by using genome sequencing data on a large set of germplasm lines. The genetic loci and the genes that were identified could help improve phosphorus use and acquisition efficiency in chickpea. Additionally, understanding the genetics of root traits encoding phosphorus acquisition efficiency and phosphorus use efficiency will help develop strategies to reduce fertiliser application around the world and especially in developing countries. The molecular markers and genes identified in this research will be used to develop chickpea genotypes with improved phosphorus acquisition and use efficiencies.

This research is supported by UWA, the Department of Agriculture and Cooperation and Farmers Welfare, Government of India, and the Bill & Melinda Gates Foundation.

Green chickpea pods growing in the field.

Dr Bharadwaj Chellapilla, Sneha Priya Pappula Reddy, and Professor Madan Pal Singh at the climate-controlled facility growth chamber, Nanaji Deshmukh Plant Phenomics Centre, IARI, India.

Analysis of agro-morpho-physiological responses and comparative metabolomic and proteomics profiling of chickpea (*Cicer arietinum* L.) genotypes under terminal drought stress

Project team: Sneha Priya Pappula Reddy[1], Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au), Professor Harvey Millar[1,2], Dr Jiayin Pang[1], Dr Bharadwaj Chellapilla[1,3], Professor Madan Pal Singh[3]

Collaborating organisations: [1]UWA; [2]The ARC Centre of Excellence in Plant Energy Biology; [3]ICAR-Indian Agriculture Research Institute

Analysis of agro-morpho-physiological responses and comparative metabolomic and proteomics profiling of chickpea (*Cicer arietinum* L.) genotypes under terminal drought stress.

More than 80 per cent of chickpea is grown under rainfed conditions where unpredictable rainfall pattern or drought stress is the most common limiting factor that affects its growth and productivity. Drought stress interrupts photosynthesis and increases translocation of carbohydrates, accelerates phasic development, and accelerates senescence. Genetic improvement is the most efficient and sustainable way to reduce drought stress effect and develop genetically superior germplasm that can adapt to climate change. However, genetic improvement requires a understanding of the physio-biochemical mechanisms controlling different traits. Little is known about the complex metabolic regulation for drought stress tolerance in chickpea. The analysis of biologically important proteins and metabolites is necessary to understand their influence on molecules related to stress tolerance mechanisms in chickpea.

The specific objective of this study is to:

- determine genotypic variability in relation to agro-morphological responses of six chickpea genotypes under terminal drought stress,
- understand the changes in physiological processes associated with the pod/seed abortion and pollen sterility under drought stress,
- examine the effect of terminal drought on root growth, morphology and development, and
- demonstrate the differential accumulation of proteins and metabolites in leaf, pod and root under drought stress and identify selected proteins and metabolites in different pathways in relation to drought tolerance in chickpea.

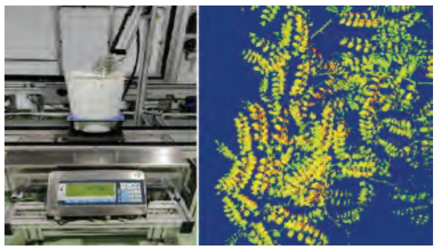
A parallel study is also being carried out for image-based, non-destructive phenotyping, using eight different imaging platforms:

- Thermal Infra-red (8000-14000nm) imaging,
- Chlorophyll fluorescence imaging,
- Unit with calibrated light source (for optional sensors – spectroradiometer/ FTIR),
- Root imaging – Near Infra-Red (900 to 1700nm) & Visible colour imaging,
- Visual colour imaging,
- Near Infra-Red shoot imaging (900 to 1700nm),
- Visible-Near Infra-Red Hyperspectral imaging (400-1000nm), and
- ShortWave Infra-Red Hyperspectral imaging (1000-2500nm).

The output data will be used to measure the early vigour, growth rate, biomass, senescence, photosynthetic pigments, photosynthesis efficiency, plant water content, water use efficiency and amount of water transpired per plant etc. in response to drought stress using advanced image processing software (Scanalyzer 3D with LemnaControl, LemnaLauncher, LemnaGrid, LemnaMiner and LemnaBase tools).

This research is supported by the Department of Biotechnology Australia-India Strategic Research Fund, Sustainability Initiatives Revolving Fund, and UWA.

Remote-control being used by Ms Reddy to lift the PVC-tubes, using custom-designed gantry hoist to decide the daily transpiration of chickpea plants in drought experimental setup.



Precise imposition of drought stress at the automated water station (left) of Nanaji Deshmukh Plant Phenomics Centre, IARI, India

A vibrant display of chickpea diversity.

A chickpea genetic variation map based on the sequencing of 3,366 genomes

Project team: Professor Rajeev Varshney[1,2,3] (project leader; rajeev.varshney@murdoch.edu.au), Professor Manish Roorkiwal[3], Dr Shuai Sun[4,5,6], Dr Prasad Bajaj[2], Dr Annapurna Chitikineni[2], Associate Professor Mahendar Thudi[2,7], Dr Narendra Singh[8], Dr Xiao Du[5], Professor Hari Upadhyaya[2,9], Dr Aamir Khan[2], Dr Yue Wang[4], Dr Vanika Garg[2], Dr Guangyi Fan[4], Professor Wallace Cowling[1], Dr José Crossa[10], Professor Laurent Gentzbittel[11], Dr Kai Peter Voss-Fels[12], Dr Vinod Kumar Valluri[2], Dr Pallavi Sinha[2], Dr Vikas Singh[2], Associate Professor Cécile Ben[11,13], Dr Abhishek Rathore[2], Dr Ramu Punna[14], Dr Muneendra Singh[2], Professor Bunyamin Tar'an[15], Adjunct Associate Professor Chellapilla Bharadwaj[1,16], Dr Mohammad Yasin[17], Dr Motisagar Pithia[18], Dr Servejeet Singh[19], Dr Khela Ram Soren[20], Dr Himabindu Kudapa[2], Dr Diego Jarquín[21], Dr Philippe Cubry[22], Associate Professor Lee Hickey[12], Dr Girish Prasad Dixit[20], Dr Anne-Céline Thuillet[22], Dr Aladdin Hamwieh[23], Dr Shiv Kumar[23], Dr Amit Deokar[14], Dr Sushil Chaturvedi[24], Aleena Francis[25], Dr Réka Howard[21], Dr Debasis Chattopadhyay[25], Professor David Edwards[1], Associate Professor Eric Lyons[25], Dr Yves Vigouroux[22], Professor Ben Hayes[12], Associate Professor Eric von Wettberg[27], Professor Swapan Datta[28], Dr Huanming Yang[4,29], Dr Henry Nguyen[30], Dr Jian Wang[5,29], Hackett Professor Kadambot Siddique[1], Dr Trilochan Mohapatra[20], Professor Jeffrey Bennetzen[10], Dr Xun Xu[5], Dr Xin Liu[5]

Hands holding chickpeas. Credit – ICRISAT

Collaborating organisations: [1]UWA; [2]ICRISAT; [3]Murdoch University; [4]BGI-Qingdao, BGI-Shenzhen, Qingdao, China; [5]BGI-Shenzhen, China; [6]University of Chinese Academy of Sciences, China; [7]Shandong Academy of Agricultural Sciences, China; [8]ICAR–Indian Institute of Pulses Research, India; [9]University of Georgia, USA; [10]CIMMYT; [11]Skolkovo Institute of Science and Technology, Russia; [12]The University of Queensland; [13]Université de Toulouse, CNRS, France; [14]Cornell University, USA; [15]University of Saskatchewan, Canada; [16]ICAR–IARI; [17]Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, India; [18]Junagadh Agricultural University, India; [19]Rajasthan Agricultural Research Institute, India; [20]ICAR–Indian Institute of Pulses Research, India; [21]University of Nebraska–Lincoln, USA; [22]Université de Montpellier, Institut de Recherche pour le Développement, France; [23]ICARDA; [24]Rani Lakshmi Bai Central Agricultural University, India; [25]National Institute of Plant Genome Research, India; [26]University of Arizona, USA; [27]University of Vermont, USA; [28]University of Calcutta, India; [29]James D. Watson Institute of Genome Science, China; [30]University of Missouri, USA

Chickpea (*Cicer arietinum* L.) is an important pulse crop for nutritional security and human health as it provides a source of protein, dietary fibre and micronutrients. As the third most-produced pulse in the word, it is cultivated in more than 50 countries including Australia and particularly in South Asia and sub-Saharan Africa. However, worldwide chickpea productivity has been stagnant for the past five decades, contributing to reduced availability and higher levels of malnutrition in developing countries.

An international team of scientists, including from UWA, catalogued the genomic diversity of chickpea. This study is expected to lead to breeding new high-yielding and more resilient varieties. Fifty-seven scientists from 41 organisations and 11 countries used genomic sequencing to map the variation in 3,171 cultivated and 195 wild chickpea accessions (unique seed samples). It is the world's largest plant genome sequencing effort of its kind. The resulting 'chickpea pan-genome' is a publicly available resource for genomics researchers and plant breeders to enhance chickpea breeding strategies for greater crop productivity, climate resilience and human health benefits.

The study provides a complete picture of genetic variation within chickpea and a validated roadmap for using the information and genomic resources to improve the crop. By employing whole genome sequencing, the researchers were able to affirm the history of chickpea's origin in the Mediterranean region, its migration to the rest of the world and how the domesticated species evolved and diverged from its wild progenitor over time. The researchers created a divergence tree (using genes present in around 80 per cent of individuals in one species) to estimate the divergence of chickpea over the last 21 million years.

The chickpea pan-genome would provide insights into the global distribution of genetic variation and show how this diversity had been shaped by domestication and selective breeding. Based on genomic prediction, the research team proposed three crop breeding strategies to enhance crop productivity and maintain genetic diversity. Using 'optimal contribution selection' pre-breeding, the predicted performance for 100-seed weight (an important trait to improve crop yield), increased by up to 23 per cent.

Although more than 80 thousand chickpea germplasm accessions are conserved in gene banks worldwide, very few have been characterised at the genome sequence level up until now. Mapping the genetic diversity is a significant and important step forward for the future of chickpea. Effective conservation, characterisation and utilisation of germplasm resources is essential to achieve the United Nations' goal of Zero Hunger by 2030.

This research is supported by the Ministry of Agriculture and Farmers' Welfare, Department of Biotechnology, Ministry of Science and Technology under the Indo-Australian Biotechnology Fund, Government of India, and the Bill & Melinda Gates Foundation.

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

NPZ Lembke in Germany has funded projects at UWA since 2000 for pre-breeding of spring canola and field peas. As a result of the NPZ canola breeding project at UWA, several new canola varieties have been released by NPZ 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 2021, NPZ added to its portfolio of projects at UWA with the signing of a research agreement to fund the operating expenses of a UWA-based PhD project to rapidly improve field peas for stem strength, black spot disease resistance, and grain yield. PhD student Felipe Castro-Urrea began his research in 2020 to evaluate new genomic selection methods in early generations to improve these important economic traits. He discovered important genetic correlations between field and glasshouse traits which will help accelerate breeding.

New methods of analysis developed in this project include multivariate analysis with pedigree and genomic relationship information, and optimal contributions selection based on an economic index.

In 2021, the canola pre-breeding project concluded a global research project with NPZ in Germany and its partner DL Seeds in Canada which revealed high rates of global genetic gain in grain yield, seed oil and protein, and blackleg disease resistance. With optimal contributions selection, the population retained high genetic diversity, and this provided confidence that the breeding program will achieve long-term genetic gain.

This research is supported by UWA and NPZ Lembke.

A drone photo from the NPZ canola breeding project field trials in Boddington in 2021.

Field pea breeding program field trial at UWA Shenton Park Field Station in 2021.

Fast-forward breeding for a food-secure world

Project team: Professor Rajeev Varshney[1,2,3] (project leader; rajeev.varshney@murdoch.edu.au), Dr Abhishek Bohra[3,4], Professor Manish Roorkiwal[2,3], Rutwik Barmukh[2], Professor Wallace Cowling[1], Dr Annapurna Chitikineni[2], Professor Hon-Ming Lam[5], Associate Professor Lee Hickey[6], Dr Janine Croser[1], Philipp Bayer[1], Professor David Edwards[1], Dr José Crossa[7], Professor Wolfram Weckwerth[8], Professor Harvey Millar[1], Dr Arvind Kumar[2], Professor Michael Bevan[8], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]ICRISAT; [3]Murdoch University; [4]ICAR-Indian Institute of Pulses Research, India; [5]The Chinese University of Hong Kong, Shatin, Hong Kong, China; [6]The University of Queensland; [7]CIMMYT, Mexico; [8]University of Vienna, Austria; [8]Norwich Research Park, UK

This collaborative research project developed a roadmap to fast-forward breeding for accelerated crop improvement and rapid delivery systems, which will lead to a food-secure world. Two papers, published in *Trends in Genetics* and *Nature Biotechnology*, were the result of a Perth-based workshop organised by IOA and ICRISAT, and attended by research institutions from Australia, India, Austria, China, Mexico and the UK.

The current world population of 7.8 billion is predicted to reach 10 billion by 2057. Future access to affordable and healthy food will be challenging, with malnutrition already affecting one in three people worldwide. The researchers recognised that global crop production systems need to expand their outputs sustainably to feed this rapidly growing human population.

The fast-forward breeding framework provided a strategy for integrating advanced technology in crop genome sequencing, phenotyping and systems biology, together with efficient trait mapping procedures and genomic prediction (including machine learning and artificial intelligence). Adopting seed input supply systems and new production and harvesting technologies would generate increased incomes for farmers and deliver better products to consumers. This would lead to establishing rapid delivery systems into global farming practices, which is required to achieve sustainable food security in the developing world.

Increasing adoption of machine learning algorithms would provide valuable data about the genetic basis and molecular mechanisms of crops. This improved understanding is crucial to develop varieties faster. The fast-forward breeding framework demonstrated that emerging breeding approaches, such as optimal contribution selection (alone or in combination with genomic selection), would enhance the genetic base of breeding programs while accelerating genetic gains. Integrating speed breeding with new-age genomic breeding technologies could relieve the long-standing bottleneck of lengthy crop breeding cycles and contribute sustainable food security.

This research is supported by UWA and ICRISAT.

Wheat is a major cereal crop that needs accelerated productivity for improved global food security.

Experiment visited by Hackett Professor Kadambot Siddique, hemp project leader Dr Zakaria Solaiman and PhD researcher Mohammad Moinul Islam.

Optimising agronomy of industrial hemp (*Cannabis sativa* L.) cultivation in south-Western Australia

Project team: Mohammad Moinul Islam[1,2], Dr Zakaria Solaiman[1] (project leader; zakaria.solaiman@uwa.edu.au), Professor Zed Rengel[1], Emerita Professor Lynette Abbott[1], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Bangladesh Jute Research Institute; DPIRD; Food, Fibre and Land International Group; Premium Hemp Australia; WA Hemp Growers' Co-op Ltd (HempGro)

Industrial hemp (*Cannabis sativa* L.) is one of the most ancient, domesticated crops cultivated for millennia. It is potentially an essential crop in Australia for fibre (extracted from stem) or oil and protein (from seeds) since being legalised in Australia from 12 November 2017. Hemp is an ideal crop because it can produce more lateral and fibrous roots in a taproot system, preventing topsoil erosion through rainfall. Its water requirements are low as the root can penetrate deeper into the soil and gets most of its water from deep layers, so it grows well in arid regions. Hemp has a high concentration of nutrients in roots and leaves that are left in the field after harvest, and thus, soil nutrients are conserved.

This project is aimed to provide the scientific basis for the industry to introduce industrial hemp into the monoculture-based crop-growing areas of south-Western Australia that will alleviate the problems of a lack of crop species to be grown in the summer months and improve production efficiency. The introduction of industrial hemp and the use of mineral-based fertilisers and biofertilisers will provide environmental sustainability in south-Western Australia. The published research outcomes, either scientific papers or PhD thesis, will enable the crop and fibre industry to refine their fertiliser and management practices.

The aims of this project are:

- To evaluate locally available and imported varieties of industrial hemp regarding various phenotypic, physiological, nutrition and yield traits.
- To determine the effects of biological and standard chemical fertilisers on soil biological fertility, nutrients availability and hemp productivity.
- To evaluate the phosphorus use efficiency of industrial hemp in low-phosphorus soil and under different P-fertilisation.

In 2021, an experiment was conducted in pots in controlled environment room at the UWA Plant Growth Facilities to determine the effect of different P-fertilisation and to evaluate the phosphorus use efficiency (PUE) of industrial hemp (*Cannabis sativa* L.).

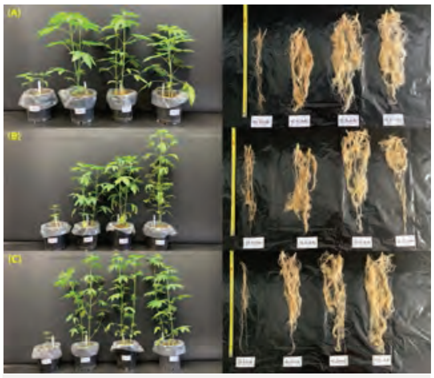
Two contrasting varieties namely, Han FNQ and Morpeth that were previously selected based on seed germination and early growth responses (Experimental Chapter 01), seed nutrition (Experimental Chapter 02) and responses to rock mineral fertilisation with microbial inoculation (Experimental Chapter 03) were used in this study along with an intermediate type of variety, Fedora 17. Effects of four different P-fertilisation (0, 40, 80 and 120 mg P.kg -1) were tested for these varieties in low-P soil (6.5 mg P.kg -1) collected from UWA Farm Ridgefield, Pingelly, WA. Plants were raised and harvested at 35 days after sowing. Several morphological and agronomic growth indices along with physiological growth indices were measured using LiCOR and SPAD.

Major macro- and micro-nutrient concentrations were also measured using ICP-OES including shoot P concentration to determine the total P content in shoots and calculate PUE of the varieties. Root growth indices and rhizosphere carboxylates activities will be also measured.

Previous studies reported that different P-fertilisation can impact the growth and yield of *Cannabis sativa* L. with greater plant width that may result in more buds per plant (Cockson et al. 2020). In medical cannabis, contrasting results were observed for cannabinoid concentrations vs. inflorescence biomass under different P-supply (Shiponi and Bernstein 2021). Veazie et al. (2021) reported no differences in biomass production and luxury P uptake by plant as fertilisation increased that indicates rates above certain P-level (15 mg·L-1) are not beneficial for plant growth and add economic cost to the growers. However, data regarding the effect of different P-fertilisation on growth, yield and root carboxylates activities and phosphorus use efficiency of hemp varieties are rare.

Therefore, this experiment will provide a scientific assessment of the phosphorus use efficiency of industrial hemp in low-P soil with novel findings related to rhizosphere carboxylate activities of different hemp varieties.

This research is supported by the Australian Government International Research Training Program RTP and UWA.



Effect of different P-fertilisation (0, 40, 80 and 120 mg P.kg -1) on shoot and root growth of industrial hemp (Cannabis sativa L.) varieties: (A) Morpeth; (B) Han FNQ and (C) Fedora 17.

Nitrogen supply ameliorates cadmium stress in maize

Project team: Tingting An[2], Yujie Wu[2], Professor Bingcheng Xu[2], Professor Suiqi Zhang[2], Professor Xiping Deng[2], Professor Yi Zhang[2], Hackett Professor Kadambot Siddique[1], Dr Yinglong Chen[1] (project leader; yinglong.chen@uwa.edu.au)

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

Soil cadmium (Cd) contamination is a serious problem on agricultural land in many countries. Adequate nitrogen (N) supply may help ameliorate plant fitness under Cd stress. This collaborative project examined the role of N application in improving maize tolerance to Cd stress. Two maize genotypes, Zhongke11 (larger root system) and Shengrui999 (smaller root system), were grown in a loessal soil amended with Cd (20 mg/kg soil as $CdCl_2 \cdot 2.5H_2O$) and N (100 mg/kg soil as urea) or without Cd and N addition. Maize plants were assessed at the silking and maturity stages.

The study showed that plants exhibited moderate Cd stress with significant reduction in grain yield, especially under low N. Roots accumulated more Cd than above-ground parts. Grain Cd concentration was the least among all organs that were below the safety threshold. Leaf Cd concentrations were also under the toxicity threshold. Nitrogen addition significantly improved plant growth, chlorophyll content, photosynthesis parameters, and tissue Cd contents, and reduced Cd concentration in soil compared to nil N treatment. Nitrogen promoted the Cd bioconcentration and translocation factors in stem and leaves. Cadmium stress reduced N fertiliser agronomic efficiency at maturity. Root Cd content was positively correlated with root N and calcium accumulation at the maturity stage, and stem Cd content was positively correlated with stem N content ($P \leq 0.05$).

This study demonstrated that the two maize genotypes with different root system architecture differed in the response to Cd toxicity and N deficit. The small-rooted genotype Shengrui999 was more tolerant to moderate Cd stress than the large-rooted Zhongke11. Addition of N ameliorated Cd stress in both maize genotypes by improving plant growth performance and regulating Cd translocations among plant organs. The mechanisms underlying N-mediated amelioration Cd stress in maize are under investigation using transcriptome and metabolome analysis.

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

Maize plants grown in a rain shed under nitrogen and cadmium treatments.

Evaluation and development of castor bean as a commercial crop in Australia

Project team: Dr Yinglong Chen[1], Associate Professor Maggie Ying Jiang[1], Adjunct Professor Tanveer Khan[1], Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au)

Collaborating organisation: [1]UWA

Castor bean (*Ricinus communis* L.) plants produce seeds rich in high-quality castor oil, which is widely used in manufacture of nylon fibres, jet engine lubricants, hydraulic fluids. In this project, our studies identified genotypic variation in phenology (time to flowering and maturity), seed yield, and the tolerance to drought and salt stress among castor bean genotypes. One of the objectives of this project is to develop hybrid lines with improved seed yield and better adaptation to abiotic stress.

The crossing study was carried out in a screen house at the UWA Shenton Park Field Station. The imported Chinese cultivars Zibo and three wild types from Perth surroundings were selected from our recent experiments conducted at glasshouse, field station and farmland at Marvel Loch. Since different lines flower at different time, synchronising flowering was a challenge. It was interesting to see that the apical raceme often has both male and female flowers, and some secondary branches only produce male flowers or a greater tendency of male flowers and in some cases only female flowers.

Practical measures including staggered planting, increased plant numbers per line and isolations of plants during the flowering stage were attempted during the study. Sterilised forceps, scissors and other tools were used to remove flowers and transfer male flower raceme for pollination. Care was taken to carefully remove flowers of the opposite sex to avoid self-pollination After pollination, the whole raceme on the main stem was bagged, and seeds were collected at maturity. Collected seeds are being planted in a glasshouse at UWA Crawley campus for collecting F1 generation seeds for future testing and planting.

Through hybridization and selection of a wide range genetic materials, this study will produce new cultivars for better adaptation to the environments with various abiotic stresses in WA.

This research is supported by the Virtue Australia Foundation.

Castor bean plant showing bagged hybrid seed pods on the main stem.

Na+ and/or Cl- toxicities determine salt sensitivity in soybean (*Glycine max* L.) Merr.), Mungbean (*Vigna radiata* L.) R. Wilczek), cowpea (*Vigna unguiculata* L.) Walp.), and common bean (*Phaseolus vulgaris* L.)

Project team: Dr Ly Thi Thanh Le[1,2], Dr Lukasz Kotula[1], Hackett Professor Kadambot Siddique[1], Professor Timothy Colmer[1] (project leader; timothy.colmer@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]Field Crops Research Institute, Vietnam

Grain legumes are important crops, but they are salt sensitive. This research dissected the responses of four (sub) tropical grain legumes to ionic components (Na+ and/or Cl-) of salt stress. Soybean, mungbean, cowpea, and common bean were subjected to NaCl, Na+ salts (without Cl-), Cl- salts (without Na+), and a "high cation" negative control for 57 days. Growth, leaf gas exchange, and tissue ion concentrations were assessed at different growing stages.

For soybean, NaCl and Na+ salts impaired seed dry mass (30 per cent of control), more so than Cl- salts (60 per cent of control). All treatments impaired mungbean growth, with NaCl and Cl- salt treatments affecting seed dry mass the most (2 per cent of control). For cowpea, NaCl had the greatest adverse impact on seed dry mass (20 per cent of control), while Na+ salts and Cl- salts had similar intermediate effects (~45 per cent of control). For common bean, NaCl had the greatest adverse effect on seed dry mass (4 per cent of control), while Na+ salts and Cl- salts impaired seed dry mass to a lesser extent (~45 per cent of control). NaCl and Na+ salts (without Cl-) affected the photosynthesis (Pn) of soybean more than Cl- salts (without Na+) (50 per cent of control), while the reverse was true for mungbean. Na+ salts (without Cl-), Cl- salts (without Na+), and NaCl had similar adverse effects on Pn of cowpea and common bean (~70 per cent of control).

In conclusion, salt sensitivity is predominantly determined by Na+ toxicity in soybean, Cl- toxicity in mungbean, and both Na+ and Cl- toxicity in cowpea and common bean.

This research is supported by the RTP Scholarship, APA, UWA Safety-Net Top-Up Scholarship, and Underwood PhD Completion Scholarship.

A ripe soybean plant (*Glycine max* L.) in the field.

Dr Ly Thi Thanh Le at the UWA Crawley campus.

Integrated farming with intercropping increases food production while reducing environmental footprint

Project team: Qiang Chai[2] (project leader; chaiq@gsau.edu.cn), Dr Thomas Nemecek[3], Chang Liang[4], Cai Zhao[2], Dr Aizhong Yu[2], Professor Jeffrey Coulter[5], Dr Yifan Wang[2], Dr Falong Hu[2], Dr Limin Wang[2], Hackett Professor Kadambot Siddique[1], Professor Yantai Gan[6]

Collaborating organisations: [1]UWA; [2]Gansu Agricultural University, China; [3]Agroscope, LifeCycle Assessment Research Group, Switzerland; [4]Pollutant Inventories and Reporting Division, Environment and Climate Change Canada; [5]University of Minnesota, USA; [6]Swift Current Research and Development Centre, Canada

This international collaborative project identified how smallholder farms can grow more food with a reduced carbon footprint by adopting integrated farming systems. The world has been struggling to find sustainable ways to produce more food for an ever-increasing human population with fewer negative environmental impacts. The challenge is magnified in countries or regions where the availability of farmable land for agriculture is limited. About 83 per cent of the global agricultural population (more than 2.3 billion people) rely on smallholder family farms for their livelihood.

An added challenge for agriculture is the uncertainty of the consequences of climate change and unpredictable abiotic stresses, which put pressure on agriculture to produce affordable food in sufficient quantities with minimal negative impact on the environment. In developing countries, the lack of resources and available farmable land for agriculture has meant that many people are undernourished due to the lack of sufficient food. In more developed countries, the excessive use of synthetic fertilisers and other agro-chemicals have negatively impacted the environment.

In China for example, excessive use of synthetic nitrogen fertilisers has increased greenhouse gas emissions, lowered nutrient-use efficiencies, and increased the risk of soil acidification and water and soil pollution.

Through 16 field experiments conducted over 12 consecutive years, the researchers found that smallholder farmers could achieve the dual goal of growing more food and lowering the environmental footprint by adopting integrated farming systems. The research team developed an integrated cropping system that incorporated four components for farmers to follow: intensified cropping systems, relay planting within-field strip rotation, soil mulching with available means, and no-till or reduced tillage.

Adopting the 'system integration' model would have an immediate and significant impact on the global agricultural sector. The research showed that system integration generates significant synergies. When compared with traditional monoculture cropping, it increases annual crop yields by 15.6 to 49.9 per cent and farm net returns by 39.2 per cent. The integrated cropping system decreases the environmental footprint by 17.3 per cent.

This research is supported by the Gansu Provincial Key Laboratory of Aridland Crop Science, Gansu Agricultural University, Innovation Group of Basic Research in Gansu Province, National Natural Science Foundation of China, and Modern Agro-Industry Technology Research System.

Cereal-pulse (maize and field pea) intercropping in Wuwei, Gansu Province, China.

Agricultural land-use favours Mucoromycotinian, but not Glomeromycotinian, arbuscular mycorrhizal fungi across ten biomes

Project team: Dr Felipe Albornoz[1,2] (project leader; felipe.albornoz@uwa.edu.au), Professor Megan Ryan[1], Associate Professor Deirdre Gleeson[1], Professor Gary Bending[3], Dr Sally Hilton[3], Professor Ian Dickie[4], Associate Professor Rachel Standish[5]

Collaborating organisations: [1]UWA; [2]CSIRO; [3]University of Warwick, UK; [4]University of Canterbury, NZ; [5]Murdoch University

This world-first collaborative study directly compared the abundance and richness of two groups of root-colonising fungi across a diverse set of Australian biomes. Globally, there is increasing interest in the role of the soil microbes in sustainable agriculture systems. Arbuscular mycorrhizal fungi (AMF) colonise the roots of most plant species and are considered an essential component of natural and agricultural systems due to their important role in plant and soil health. However, industrialised agriculture is considered to have a negative impact on AMF.

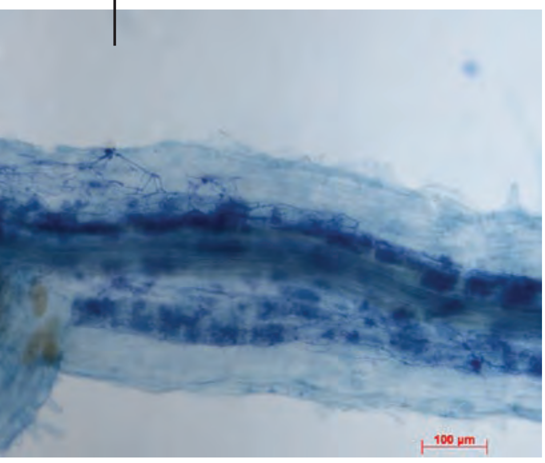
Recently, research at UWA showed AMF include fungi in the subphylum Mucoromycotina as well as in the well-known Glomeromycotina. Very little is known about how these two groups of AMF differ and whether they play contrasting roles in natural and agricultural systems. To investigate the impact of agriculture on both groups of AMF, the research team collected roots from paired agricultural and natural sites across 10 Australian biomes – from the tropical savannah of the Northern Territory to the montane forests of Tasmania to the Mediterranean shrublands of Western Australia. DNA extracted from the roots was sequenced and used to characterise the communities of AMF. In contrast to expectations, the study showed that agricultural land-use favoured Mucoromycotinian AMF, with these fungi being of low abundance or absent in native ecosystems, and largely absent from northern tropical biomes.

Further research is needed to quantify the role of Mucoromycotinian AMF in crop growth in southern Australia. Another key avenue for future research is the origin and spread of these fungi across Australia.

This research is supported by the ARC Discovery Project and the UK Natural Environment Research Council.

Dr Felipe Albornoz, Associate Professor Rachel Standish and Professor Gary Bending sampling a corn crop on the Atherton Tablelands in Queensland. Credit: Professor Megan Ryan

Colonised root showing characteristic thin hyphae and fine-branched arbuscules of Mucoromycotinian AMF. Credit: Dr Jeremy Bougoure



Blending biosolids with other waste streams to optimise nutrient ratios and restore and stabilise carbon in Australian cropping soils

Project team: Professor Megan Ryan[1] (project leader; megan.ryan@uwa.edu.au), Associate Professor Michael Burton[1], Professor Anas Ghadouani[1], Professor Susanne Schmidt[2], Distinguished Professor Andy Ball[3]

Collaborating organisations: [1]UWA; [2]University of Queensland; [3]RMIT University; Richgro; South East Water; Water Research Australia

In this project we are investigating if engineered biosolids can be used to produce a safe and affordable (transportable) fertiliser product, with optimal ratios of key nutrients, to aid the formation of stable organic carbon in the soils of the broadacre cropping systems across southern Australia. We will also investigate how these human waste derived fertiliser products fit within the retail and agricultural marketplaces.

In this 2b theme, Dr Bede Mickan and PhD student George Mercer commenced under Professor Megan Ryan and the first batch of plant growth experiments were started in mid-2021. Data from these experiments is positive, and we are looking forward to translating these scientific outcomes to the industry partners, farmers, and the scientific community in 2022. Associate Professor Michael Burton and Honours student Jacky Lu conducted an in-depth survey on the public perception of how biosolids-derived fertilisers are likely to be accepted as a fertiliser.

This research is supported by UWA.

Biosolids are the major by-product of the wastewater treatment process. Pictured is biosolid 'dewatering' at a treatment plant.

Farm demonstration to fast-track restoration of soil condition using permeable biomass barriers

Project team: Emerita Professor Lynette Abbott[1] (project leader; lynette.abbott@uwa.edu.au), Karry Fisher-Watts[2], Cheryl Rimmer[1], Dr Sasha Jenkins[1], Dr Zakaria Solaiman[1], Cassandra Howell[1]

Collaborating organisations: [1]UWA; [2]Treōwstede Brookton; Wheatbelt NRM; NutraRich Brookton; Shire of Brookton; Pingelly CRC

This farm demonstration project is being funded through the National Landcare Program Smart Farms Small Grants. The project is focussed both on capacity-building for sustainable natural resource management as well as undertaking and fostering sustainable natural resource management best practice.

The project uses a large-scale field demonstration to show how up-scaling of novel soil restoration practices can re-establish productivity on degraded areas of farmland. A field demonstration has been established on pasture exposed to localised salinity and erosion at UWA Farm Ridgefield.

The practices being trialled involve permeable biomass (waste organic material) barrier wells and walls to fast-track restoration of degraded salt-affected soil subjected to potential further erosion. The 'permeable wells' (post-holes approximately 40cm deep) were placed adjacent to trees and 'permeable walls' (sequential parallel slots 40cm deep, 150cm wide) were placed strategically to intercept surface shallow saline water flow. The wells and walls were filled with mixtures of organic materials including locally sourced compost, biochar, straw and other available organic (waste) materials. Biological inoculants from materials such as manures, composts, wood vinegar and worm juice have also been incorporated into the wells and walls at the time of establishment and subsequently.

It was demonstrated that the permeable wells could provide a nutrient resource pool for roots from the adjacent shrubs/trees to access. Proliferation of roots in the wells containing biological amendments could gain access to a perpetual nutrient resource. The permeable walls and associated disturbance of the severely degraded soil altered the soil conditions and enabled the successful establishment of two tree seedlings (saltbush and Eucalypt) in the field.

Overall, strategic placement of soil biological amendments in permeable wells and walls demonstrated the potential to improve productivity of trees and shrubs planted in degraded areas on farms and to limit the potential of ongoing erosion. The field demonstration site established at UWA Farm Ridgefield will be available for further investigation by students and for field days, with potential to monitor the ongoing efficacy of the wells and walls now established at this field site.

This research is supported by UWA and the Australian Government's NLP Smart Farms Small Grants.

Emerita Professor Lynette Abbott addresses the crowd at the soil restoration demonstration site during the UWA Farm Ridgefield 2021 Open Day.

Native fungus could unlock residual phosphorus bank in soil

Project team: Dr Khalil Kariman[1] (project leader; khalil.kariman@uwa.edu.au), Professor Zed Rengel[1], Dr Craig Scanlan[2]

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

This project aims to exploit the biofertiliser potential of the Australian native fungus *Austroboletus occidentalis*, which has been shown to significantly increase crop growth, phosphorus nutrition and grain yield under both controlled environment and field conditions.

The native fungus has the potential to boost plant growth and nutrition and induce stress tolerance (for example, against drought) in host plants. This is likely linked to evolution of the fungus in the nutrient-poor and harsh jarrah forest ecosystem of south-west of WA. The fungus needed to be resilient to a variety of soil constraints such as nutrient deficiency (phosphorus, in particular), high metal contents and pH extremes, as well as environmental stresses like drought and heat.

As part of this GRDC-funded project, the researchers are looking into how to exploit this novel biofertiliser for agricultural crops, and in turn, minimise the use of synthetic phosphorus fertilisers and their environmental footprint.

Mineral phosphorus fertilisers are one of the major inputs to support high crop yields. However, a major percentage of the applied phosphorus fertilisers can be immobilised in soil due to adsorption by soil particles and organic matter, or chemical fixation through binding with metals. This leads to an ongoing accumulation of residual phosphorus in crop fields, which is mostly inaccessible to plant roots. It is crucial to find an environmentally friendly solution to tap into this huge residual phosphorus bank in field soils.

This research is supported by GRDC and UWA.

Dr Khalil Kariman with a colony of the native fungus Austroboletus occidentalis.

Development of 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

Led by UWA Emerita Professor Lynette Abbott, development of the SOILHEALTH app 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.

The SOILHEALTH app is due to launch in the first half of 2022.

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

UWA Emerita Professor Lynette Abbott, Communications Officer Cheryl Rimmer and Alex Lush.

Ammoniated straw incorporation improves wheat production and soil fertility

Project team: Associate Professor Yue Li[2,4], Dr Hao Feng[2,3] (project leader; qgdong2011@163.com), Dr Qin'ge Dong[2,3], Dr Longlong Xia[5], Dr Jinchao Li[2], Dr 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], Dr 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, Garmisch-Partenkirchen, Germany; [6]China Agricultural University, China; [7]Aarhus University, Denmark

This international study determined that ammoniated straw incorporation (ASI) treatment significantly improves wheat crop production and soil fertility. ASI is a process by which ammonia is added to stubbles/straw, which degrades the lignin and enhances nutrients for it to be more easily broken down by soil microbes.

The researchers investigated the responses of soil properties, wheat yield and yield stability of wheat to ammoniated and conventional straw incorporation in the China's Loess Plateau. The three treatments applied in the study were straw (the control), conventional straw incorporation (CSI), and ASI. Averaged across the three years, the ASI treatment had significantly higher soil water storage, grain yield and yield stability compared to the CSI and control treatments.

The ASI treatment increased wheat yield by 10.1 per cent and yield stability by 19.5 per cent compared to the CSI treatment. Changes in wheat yield and yield stability were positively related to ASI-induced increases in soil water storage in the dryland environment of Loess Plateau. When compared to the CSI treatment, the ASI treatment increased soil organic carbon (SOC) content by 14.2 per cent and total nitrogen (TN) content by 18.3 per cent in 0–10 cm depth, and increased SOC content by 12.4 per cent and TN content by 19.4 per cent in 10–20 cm depth.

It was determined that the ASI treatment was a very promising option for targeting sustainable agriculture in the dryland cropping regions of Australia. The results provided clear and strong evidence that ASI could achieve higher grain yield and yield stability while increasing organic carbon and total nitrogen content in the soil. However, the underlying mechanisms – particularly the microbial mechanisms— were largely unclear at the study site. Investigating the environmental effects, such as greenhouse gases emissions and nitrogen leaching, are required before applying this knowledge to large 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.

Effects of different continuous fertiliser managements on soil total nitrogen stocks in China: A meta-analysis

Project team: Dr Pengfei Dang[2], Dr Congfeng Li[3], Dr Tiantian Huang[2], Chen Lu[2], Professor Yajun Li[2] (project leader; xiaoliangqin2006@163.com), Dr Xiaoliang Qin[2], Hackett Professor Kadambot Siddique[1]

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

Soil total nitrogen is critical for crop productivity and related to agricultural managements. However, the effects of different fertiliser applications on soil total nitrogen storage are not well understood. To quantify soil total nitrogen storage under different fertiliser management practices and explore the effects of climate, soil texture, experimental duration, and cropping system on soil total nitrogen storage in China, we conducted a meta-analysis of 67 fertiliser management strategies from experiments conducted over a period of at least three years.

This meta-analysis included 854 observations of changes in soil total nitrogen stock (TNS) under no fertiliser application (control, CK), chemical fertilisation with nitrogen, phosphorus, and potassium (CF), CF plus straw retention (CFS), and CF plus manure addition (CFM) relative to initial soil TNS.

The CFM and CFS treatments increased soil TNS, and the CFM treatments increased soil C/N ratio the most. The longer the experimental duration, the greater the increase in soil TNS in the CF, CFS, and CFM treatments. Soil texture and crop type significantly affected the changes in soil TNS. The experimental duration, initial soil TNS, soil C/N ratio, and cropping system had significant linear correlations with the change in soil TNS. Temperature and precipitation were not correlated with soil TNS. Results of random forest modelling indicated that the most important factor affecting changes in soil TNS was experimental duration (positive correlation), followed by initial soil TNS (negative correlation). The CFM treatments had the largest increase in soil TNS under various conditions. We recommend promoting CFM to improve soil fertility in farmlands globally.

This research is supported by the China Agriculture Research System of MOF and MARA, and the National Natural Science Foundation of China.

Three different kinds of chemical fertiliser pictured next to plant roots.

Nutrients leaching from tillage soil amended with wheat straw biochar influenced by fertiliser type

Project team: Cheng Huang[1,2,3], Dr Xiuyun Sun[2], Professor Lianjun Wang[2], Paul Storer[4], Hackett Professor Kadambot Siddique[1], Dr Zakaria Solaiman[1] (project leader; zakaria.solaiman@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]Nanjing University of Science and Technology, China; [3]Jiangsu University of Science and Technology, China; [4]Troforte Innovations

The co-application of biochar and fertiliser has emerged as a strategy for improving soil quality and crop growth; however, the impact of the type of fertiliser added with biochar to the soil on leaching and retention of nutrients is not well studied. In this study, a leaching experiment was undertaken using a series of column lysimeters incorporating a wheat straw biochar (WSB) and two fertiliser types—chemical fertiliser (CF), or rock mineral fertiliser (MF).

The results showed that CF and MF leached a similar amount of $NH4+$ with or without WSB, but the $NO3-$ leaching occurred from CF-treated soil which was decreased by CF + WSB application. In contrast, $NO3-$ leaching was not affected by WSB in MF-treated soil. Both CF and MF with or without WSB increased the cumulative leaching of P and K. Nevertheless, WSB application increased soil P and K contents after leaching, which was attributed to intrinsic nutrient release from biochar. Shoot growth and P and K uptake also increased with biochar amendment, whereas root growth and N uptake did not change.

Therefore, the results highlight that biochar addition can improve nutrient retention and plant growth by reducing nutrient leaching, mainly dependent on biochar and fertiliser type combination used. It suggests that the adsorption properties of biochar for nutrient retention and subsequent release need to know before their broad application to soils as amendments.

This research is supported by UWA and The Science and Technology Department of Jiangsu Province, China.

Biochar is a carbon-rich material derived from waste materials such as animal manure, crop residues and sewage sludge.

The effects of biochar and a biochar-compost mix on growth, performance and physiological responses of potted *Alpinia zerumbet*

Project team: Faisal Zulfiqar[2] (project leader; ch.faisal.zulfiqar@gmail.com), Professor Xiangying Wei[3], Narmeen Shaukat[4], Professor Jianjun Chen[5], Dr Ali Raza[6], Dr Adnan Younis[4], Dr Muhammad Nafees[2], Dr Zainul Abideen[7], Abbu Zaid[8], Nadeem Latif[2], Associate Professor Muhammad Naveed[4], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]The Islamia University of Bahawalpur, Pakistan; [3]Minjiang University, China; [4]University of Agriculture Faisalabad, Pakistan; [5]University of Florida, USA; [6]Fujian Agriculture and Forestry University, China; [7]University of Karachi, Pakistan; [8]Aligarh Muslim University, India

Container crop production has become increasingly popular over the last 50 years. A major component of container or potting media is peat. Peatlands are a natural carbon sink, and peat is a non-renewable natural resource. Peat harvesting has become an important environmental issue. There is a growing effort to explore alternative organic materials to completely or partially replace peat as a medium component. Biochar is a carbon-rich product that has gained increasing interest as a component of growing media.

In the present study, biochar was produced from rice straw. Peat/perlite/biochar and peat/perlite/biochar/vermicompost were evaluated relative to a basal or control medium of peat/perlite.

The fruit of *Alpinia zerumbet* (shell ginger).

Alpinia (*Alpinia zerumbet* 'Variegata Dwarf') was used as a test plant. Amending biochar and biochar–compost mix increased the pH of the growing media. Hydrophysical properties including container capacity, bulk density, air space and total porosity were all within or near the standard ranges for soilless growing media. Chlorophyll a and b contents of *A. zerumbet* plants grown in PPB medium were reduced by more than 20 per cent and 28 per cent, respectively, compared to those grown in PP or PPBC media. The net photosynthetic rate of PPB-grown plants was more than 28 per cent lower than those grown in PP and PPBC media. As a result, shoot and root dry weights of plants produced in PPB medium were more than 42 per cent and 22 per cent less, respectively, than those grown in PP and PPBC media. Although visual quality of PPB-grown plants was lower, they still exhibited marketable quality, which was largely because their side shoots, leaf numbers, leaf areas, leaf thickness, and shoot diameters were comparable to those produced in PP and PPBC media.

The study showed that in a peat/perlite basal medium, substitution of peat by biochar derived from rice straw at 30 per cent affected the growth of *A. zerumbet* plants, mainly in dry matter accumulation, but the plants were still marketable. On the other hand, plants grown in the same basal medium with peat replaced by the biochar at 35 per cent plus an amendment of compost at five per cent were comparable to those grown in the control medium. As the value of ornamental plants depends on their aesthetic appearance, a potting medium comprised of peat/perlite/biochar/vermicompost at 30/30/35/5 by volume is recommended for the production of *A. zerumbet* plants. The substitution of peat at 35 per cent suggests that peat use can be reduced in the formulation of potting media, thus contributing to the conservation of peatlands.

Antimony contamination and its risk management in complex environmental settings: A review

Project team: Professor Nanthi Bolan[1] (project leader; nanthi.bolan@uwa.edu.au), Dr Manish Kumar[2], Dr Ekta Singh[2], Dr Aman Kumar[2], Dr Lal Singh[2], Dr Sunil Kumar[2], S Keerthanan[3], Son A Hoang[4], Dr Ali El-Naggar[5], Professor Meththika Vithanage[3], Dr Binoy Sarkar[6], Dr Hasintha Wijesekara[7], Dr Saranga Diyabalanage[3], Prasanthi Sooriyakumar[4], Professor Ajayan Vinu[4], Dr Hailong Wang[8], Professor M B Kirkham[9], Dr Sabry M Shaheen[11,12,13], Dr Jörg Rinklebe[14,15], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]CSIR-National Environmental Engineering Research Institute, India; [3]University of Sri Jayewardenepura, Sri Lanka; [4]The University of Newcastle; [5]Ain Shams University, Egypt; [6]Lancaster University, UK; [7]Sabaragamuwa University, Sri Lanka; [8]Foshan University, Foshan, China; [9]A&F University, China; [10]Kansas State University, USA; [11]University of Wuppertal, Germany; [12]King Abdulaziz University, Saudi Arabia; [13]University of Kafrelsheikh, Egypt; [14]University of Wuppertal, Germany; [15]Sejong University, Korea

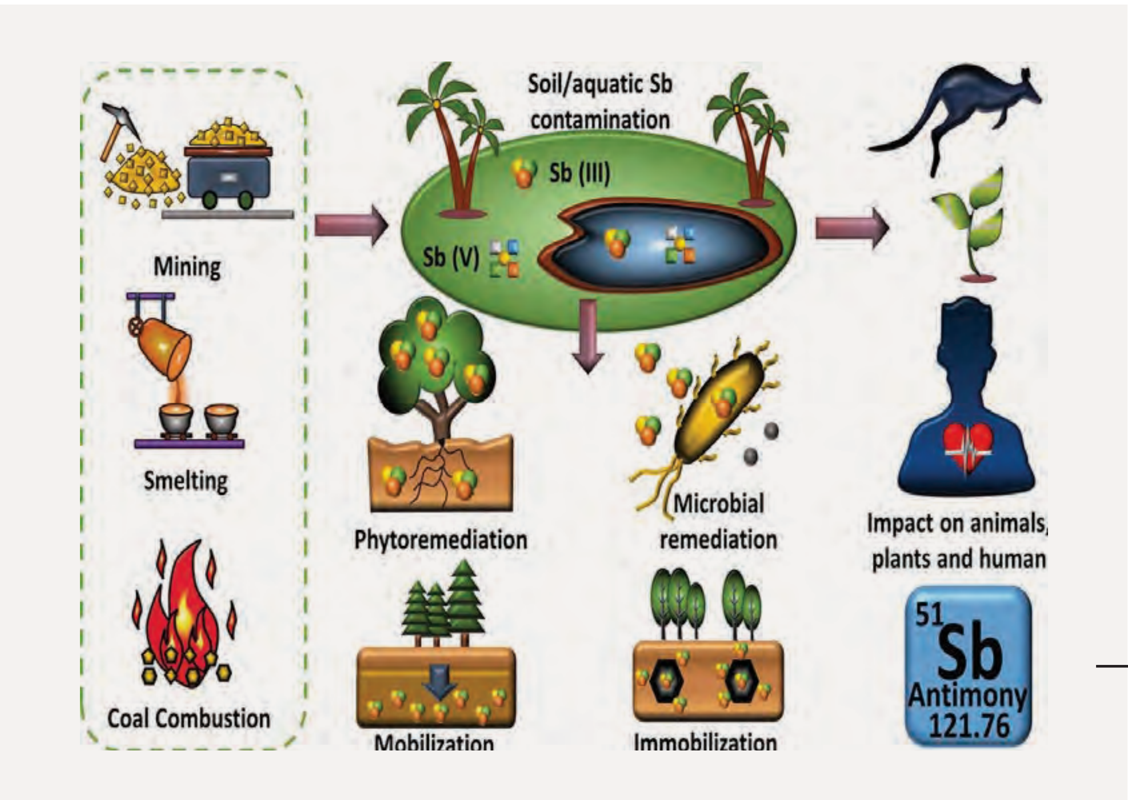
Antimony (Sb) is introduced into soils, sediments, and aquatic environments from various sources such as weathering of sulfide ores, leaching of mining wastes, and anthropogenic activities. High Sb concentrations are toxic to ecosystems and potentially to public health via the accumulation in food chain. Although Sb is poisonous and carcinogenic to humans, the exact mechanisms causing toxicity remain unclear. Most studies concerning the remediation of soils and aquatic environments contaminated with Sb have evaluated various amendments that reduce Sb bioavailability and toxicity. However, there is no comprehensive review on the biogeochemistry and transformation of Sb related to its remediation.

Therefore, the research review summarises:

- The sources of Sb and its geochemical distribution and speciation in soils and aquatic environments,
- The biogeochemical processes that govern Sb mobilisation, bioavailability, toxicity in soils and aquatic environments, and possible threats to human and ecosystem health, and
- The approaches used to remediate Sb-contaminated soils and water and mitigate potential environmental and health risks. Knowledge gaps and future research needs also are discussed.

The review presents up-to-date knowledge about the fate of Sb in soils and aquatic environments and contributes to an important insight into the environmental hazards of Sb. The findings from the review should help to develop innovative and appropriate technologies for controlling Sb bioavailability and toxicity and sustainably managing Sb-polluted soils and water, subsequently minimising its environmental and human health risks.

This research is supported by the Open Access Publication Fund of the University of Wuppertal, Germany, National Key Research and Development Program of China, and National Natural Science Foundation of China.



The graphical abstract for this review paper.

Observing cattle after collars applied in the BeefLinks Virtual Fencing project. Bandit the dog, Hamersley Station manager Evan Casey, Pastoral Station Rio Tinto manager Sim Mathwin, and UWA's Dr Peter Hutton and Dr Zoey Durmic.

2

Sustainable Animal Production Systems

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

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

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

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

Theme Leaders

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PhD students Callum Connolly and Tayler Kent assessing ram sperm samples in a transient field lab at UWA Farm Ridgefield.

Redefining ovine 'clover disease': A modern perspective on phyto-oestrogens and sheep 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 Caitlin Wryroll[1], Mia Kontoolas[1], Jeremy Smith[1], Professor Philip Vercoe[1], Emeritus Professor Graeme Martin[1], Dr Tim Watts[1], Daniel Kidd[1], Luoyang Ding[1], Tayler Kent[2]

Collaborating organisations: [1]UWA; [2]Murdoch University; Curtin 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. This syndrome, termed clover disease, remains difficult to detect and manage due to a lack of recent research. Furthermore, whilst there is a plethora of studies in the ewe, there is very little information surrounding phytoestrogen exposure in the ram. Despite this lack of information, in Australia it is currently considered safe for breeding rams to graze oestrogenic pastures.

During 2021, funded by the Lefroy bequest for research in Merino sheep, we finished up our study into clover disease in the ram. 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. For the first time we demonstrate that phytoestrogens alter ram reproductive function and provide evidence of a mechanism for this event.

We have had the opportunity to convey some of this information to producers and industry partners in WA during conferences in Southern WA. This project has so far produced two publications, with a third expected by August 2022.

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 The E.H.B Lefroy Research Fellowship Bequest and MLA.

PhD students Callum Connolly and Luoyang Ding and Dr Kelsey Pool with the research rams at UWA Farm Ridgefield.

Can exogenous melatonin improve twin lamb welfare and production via in utero exposure?

Project team: Dr Kelsey Pool[1] (project leader; kelsey.pool@uwa.edu.au), Associate Professor Dominique Blache[1], Professor Shane Maloney[1], Luoyang Ding[1], Dr Tim Watts[1], Dr Caitlyn Wryrwroll[1], Dr Mark Hackett[2]

Collaborating organisations: [1]UWA; [2]Curtin University; Ceva Animal Health Australia

In many mammalian species, including sheep, twin pregnancies result in reduced fetal oxygen supply, injurious births and restricted growth. The consequences of this include offspring with hypoxia, compromised cognitive function and higher mortality rates, raising concerns for both productivity and animal welfare.

The neurohormone melatonin is well-established as the regulator of seasonal fertility in sheep. Melatonin is also a potent antioxidant, controls vascular growth and available as a slow-release implant to improve ovine fertility. These properties make it an ideal candidate to mitigate the inherent issues in twin-pregnancies.

This project aimed to determine if treating twin-bearing ewes with slow-release melatonin implants, at a commercial scale, improves lamb production, physiological function and cognition.

To date, this work has demonstrated that treatment of twin-bearing ewes with melatonin improves twin lamb production and welfare outcomes. Specifically, vascular communication between ewe and lamb is increased, lambs demonstrate greater brown fat percentage, greater body weight at key husbandry periods, have superior leaning ability, vocalisation and are more inquisitive, have a higher brain mass and superior immune function.

This work has immediate commercial application, as slow-release melatonin implants are already registered for commercial use in sheep. The use of this protocol may improve twin lamb production and welfare outcomes in sheep production systems within Australia.

This project has been presented at three industry forums.

This research is supported by The E.H.B Lefroy Research Fellowship Bequest and Ceva Animal Health Australia (donation of product).

Dr Tim Watts and the UWA team checking which ewes have successfully lambed at Mederberrin farm.

Dr Kelsey Pool and Pingelly sheep producer Lachlan Watts checking the research lambing paddocks at Mederberrin farm.

Australian Merino sheep with their lambs.

Improving productivity reduces methane intensity but increases the net emissions of sheepmeat and wool enterprises

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

Collaborating organisations: [1]UWA; [1]CSIRO

Greenhouse gas emissions from Western Australia's sheep flock account for 26 per cent of the state's agricultural emissions, principally as a result of enteric methane emissions. A decrease in emissions between 2005 and 2019 can be partly explained by a 44 per cent drop in sheep numbers over that period, but less is known about potential changes in the methane intensity of sheepmeat and wool kg CO2 equivalents/kg product.

Here, we evaluate changes in the methane intensity of sheepmeat and wool produced in two major sheep producing regions in Western Australia between 2005 and 2019. We also simulate a range of future scenarios to evaluate potential future methane intensity and net methane emissions trajectories. Our results demonstrate that as improvements in enterprise productivity have been made, increasing production per ewe and per hectare, the methane intensity of sheepmeat and wool produced has declined, by 11.1 per cent between 2005 and 2019, and is forecast to decline further by as much as 42 per cent compared to 2005. However, there is a largely inverse relationship between methane intensity and net enterprise emissions which have increased by 11.6 per cent, between 2005 and 2019, and may increase in future by as much as 62 per cent.

These results demonstrate that unless enterprise/state flock numbers are constrained improved productivity will reduce methane intensity but will increase net emissions. Sheep producers currently have few options available to reduce net emissions though optimising productivity. However, more efficient producers, who produce lower emission products, would be more resilient to carbon pricing or better placed to benefit from potential preferential market access. At the industry level, this highlights the importance of pursing pathways other than increased productivity as the primary means of reducing net emissions and therefore the sector's exposure to potentially unfavourable policy or market responses related to emissions.

This research is supported by UWA.

Sunset at UWA Farm Ridgefield with sheep and lambs in the field.

Investigating the development of diarrhoea through gene expression analysis in sheep genetically resistant to gastrointestinal helminth infection

Project team: Shamshad Ul Hassan[1], Adjunct Professor Johan C. Greeff[2] (project leader; johan.greeff@dpird.wa.gov.au), Dr Alfred Chin Yen Tay[1,3], Dr Eng Chua[1,3], Dr Erwin Paz[1], Associate Professor Parwinder Kaur[1], Associate Professor Shimin Liu[1], Emeritus Professor Graeme Martin[1]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]The Marshall Centre for Infectious Disease Research and Training

A major challenge faced by the sheep industry is diarrhoea caused by gastro-intestinal (GIT) helminths ('worms'), leading to major economic losses. Moreover, the helminths are developing resistance to anthelmintic medication ('drenches'). In any case, consumers are becoming wary of chemical contamination in animal products, so anthelmintics are increasingly seen as an unsustainable solution. In this general context, breeding helminth-resistant sheep had begun about thirty years ago at DPIRD. The breeding program was based primarily on selection for phenotypes with a low incidence of diarrhoea and low faecal worm egg count. This strategy has been remarkably successful at reducing the helminth burden but, unfortunately, some helminth-resistant animals are still prone to diarrhoea.

Diarrhoea is caused by an inflammatory immune response in the GIT, so we have studied the activation of inflammatory genes in sections of GIT, using next generation sequencing to measure gene expression.

In the duodenum, the first section of the small intestine and also a major site of infection, sheep that resist diarrhoea have switched on important genes that control the way the immune system responds to the presence of helminths. By contrast, in sheep that are highly susceptible to diarrhoea, the genes switched on are those that control tissue repair, in an attempt to resist damage to the digestive tract.

In the ileum, our histology studies had shown that helminth infection was associated with increased numbers of eosinophils and mast cells. This was surprising because the ileum is not the site of infection by the major helminth species. However, this initial study was supported by an analysis of gene expression.

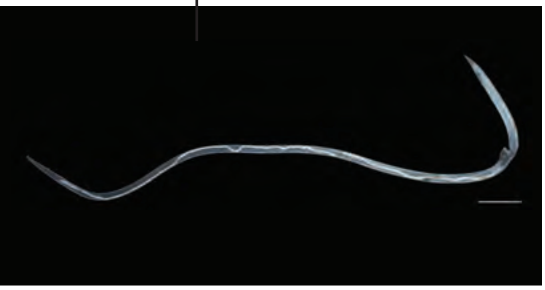
In diarrhoea-susceptible sheep, there was increased expression of key genes in inflammation and reduced expression of genes involved in ion transport. It thus seems very likely that responses in the ileum contribute to the development and severity of diarrhoea in diarrhoea-susceptible sheep.

It is becoming clear that breeding against helminth infection could be improved by including key genes involved in the immune response, in inflammation, and in the regulation of ion transport.

This research is supported by the University of Agriculture Faisalabad, UWA, Australian Wool Innovation, and DPIRD.

Shamshad Ul Hassan handling sheep at Katanning Research Facility for sample collection.

Teladorsagia circumcinta female (with a 1mm scale) are approximately double in length than their male counterparts.



Investigating gastrointestinal helminth infection in sheep – a better genome for *Teladorsagia circumcincta*

Project team: Shamshad Ul Hassan[1], Adjunct Professor Johan Greeff[2], Dr Alfred Chin Yen Tay[1,3], Dr Eng Chua[1,3], Associate Professor Peta Clode[1,4], Associate Professor Parwinder Kaur[1], (project leader; parwinder.kaur@uwa.edu.au), Emeritus Professor Graeme Martin[1]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]The Marshall Centre for Infectious Disease Research and Training; [4]Centre for Microscopy, Characterisation and Analysis

The sheep industry is challenged by several gastro-intestinal (GIT) helminths ('worms'), with *Teladorsagia circumcincta* being among the most important in south-western Australia.

To combat this worm, we need a better understanding of its biology and evolution, and how it interacts with the sheep. To this end, we need a full description of the genome *Teladorsagia circumcincta.*

Knowledge of its genes could point to new opportunities for intervening in the infection process, and perhaps lead to ideas for vaccine targets.

A 'draft' genome assembly was already available. We set out to greatly improve on the draft genome by providing a chromosome-length genome assembly. Among the substantial improvements are including the identification of six chromosome-length scaffolds, a 35 per cent reduction in number of sequences, and an increase in length of longest scaffold from 1.4 million base pairs (Mbp) to 66.6 Mbp. The corrections in the orientation of sequences and mis-joins resulted in an increased synteny with a relatively close helminth, *Haemonchus contortus.*

This research is supported by the University of Agriculture Faisalabad, UWA, DNA Zoo Consortium, and DPIRD.

Teladorsagia circumcinta male's posterior end showing bursa with a pair of copulatory spicules (mating structures found only in males, shown in brown colour in this image).

Images: Associate Professor Peta Clode from the Centre for Microscopy, Characterisation and Analysis

Re-defining 'pheromone' in the context of farm animals

Project team: Emeritus Professor Graeme Martin[1] (project leader; graeme.martin@uwa.edu.au), Professor Sarah Robertson[2]

Collaborating organisations: [1]UWA; [2]The Robinson Research Institute, University of Adelaide

The term 'pheromone' was originally coined for the insect world to define a volatile chemical used by a female to attract males, often over very long distances. It was not long before the concept was applied to mammals.

In fact, many sheep producers, particularly those that run Merinos, are making use pheromones every time they use 'teasers' to breed before February, the normal start of the breeding season. The odour of novel rams will induce ovulation in ewes that would otherwise be out of season and thus not ovulating spontaneously in regular cycles. The ram pheromone is produced by the skin and its chemistry is very poorly understood.

Now, however, we are having to rethink the pheromone concept and broaden our perspective on chemical communication between the sexes. A lot of the research driving this turnaround has come out of the University of Adelaide where they have been studying sheep, pigs, rodents and humans. Effectively, they have shown the world that semen is not just a liquid that carries sperm. Rather, it carries strong chemical signals that act on the female reproductive tract to enhance the prospect of pregnancy.

It is important to remember that the genetic makeup of the sperm and the conceptus are different to that of the prospective mother, so her immune system would see these intruders as "foreign" and therefore reject them. In other words, pregnancy would be impossible. This is where the seminal pheromones come into play. They are immune-system modulators that convince the uterus to be receptive to the embryo.

For this reason, we propose extending the definition of "pheromone" to include seminal fluid molecules that act on the female reproductive tract to enhance the prospect of pregnancy. By expanding the pheromone concept, we will gain a whole new perspective on chemical communication during reproduction in mammals, including our livestock. It is a sobering thought that those important immune molecules are lost in most artificial insemination programs when semen is greatly diluted.

This ram's semen carries sperm to fertilise eggs, and also carries chemical signals that control the ewe's uterus.

Dr Jacob Berson setting up a dung beetle trap in Serpentine, WA.

Dung Beetle Ecosystem Engineers at UWA

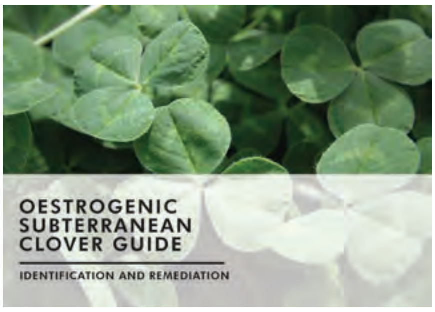
Project team: Associate Professor Theo Evans[1] (project leader; theo.evans@uwa.edu.au), Dr Jacob Berson[1], Dr Jason Kennington[1], Professor Raphael Didham[1], Professor Leigh Simmons[1], Associate Professor Ben White[1], Dr Fiona Dempster[1]

Collaborating organisations: [1]UWA; MLA; Charles Sturt University

This project is quantifying how Australian agriculture has benefited agronomically and economically from the importation of exotic dung beetles. Livestock dung remaining on pastures can be a problem for both farmers and the general public. Dung left on pasture reduces the amount of feed available for livestock and provides a breeding ground for bushflies. Dung beetles were first introduced to Australia to clean away dung fouling pastures and is considered an example of a successful biocontrol program.

A key part of this project is attempting to understand how the activity levels of the various species of dung beetles varied across seasons and the landscape. To understand the benefits of dung beetles, researchers first needed to know where they are found and when they are active. From 2018 and throughout 2021, project partners conducted monthly trapping for dung beetles at sites spread across the southern region of Australia. UWA researchers have been identifying and counting the beetles caught in their traps. The amount of data collected would not be possible without the dedication of private landholders, farmer groups and natural resource management groups conducting trapping at more than 120 locations across southern Australia. Trapping of dung beetles is expected to be completed in the first half of 2022, with results expected soon after.

This research is supported by the Federal Government Rural R&D program and MLA.



Front cover of the Oestrogenic Subterranean Clover Guide.

Oestrogenic Subterranean Clover Guide

Project team: Dr Kevin Foster[1,2] (project leader; kevin.foster@uwa.edu.au), Professor Megan Ryan[1], Daniel Kidd[1], Joe Gebbels[1,3]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]Meat & Livestock Association; Ooid Scientific

The *Oestrogenic Subterranean Clover Guide* is a collaborative project between The UWA Institute of Agriculture, DPIRD, and the MLA Donor Company as part of the project 'Maximising the reproductive potential of the meat sheep industry by eliminating high oestrogen clovers'. The purpose of the ute guide is to assist farmers to identify and remediate subterranean clover pastures that cause sheep infertility.

Subterranean clover is the most widely grown pasture legume in southern Australia. However, livestock producers are often unaware that some outdated cultivars can contain high levels of the phytoestrogen formononetin – a compound that causes fertility issues in sheep. As new cultivars have been selected for low formononetin, unfortunately, oestrogenic cultivars can be very persistent and may be hidden within older permanent pastures or have contaminated newly-sown pastures where they are difficult to distinguish from newer cultivars. Several sheep fertility and health issues can occur from grazing oestrogenic clovers, such as an increase in dry ewes at scanning or reduced lambing percentages. That link has been largely forgotten by the farming community and the resulting fertility issues may be misdiagnosed.

The guide is intended to show users how to assess the abundance of oestrogenic clovers in their pastures. If abundant, it can help them to decide whether to manage the problem or to remove the clovers through effective pasture renovation. Development of the Oestrogenic Subterranean Clover Guide took place throughout 2021 and is expected to be published in early 2022.

This research is supported by UWA, DPIRD, and the MLA Donor Company.

UWA Professor Megan Ryan, Dr Kevin Foster and Daniel Kidd with the ute guide.

Annual Legume Breeding Australia (ALBA)

Project team: Associate Professor Phillip Nichols[1] (project leader; phillip.nichols@uwa.edu.au), Professor Megan Ryan[1], Professor William Erskine[1], Wesley Moss[1], Bradley Wintle[1], Gereltsetseg Enkhbat[1], Julian van der Zanden[1]

Collaborating organisation: [1]UWA

Annual Legume Breeding Australia (ALBA) is a joint venture between UWA and the pasture seed company DLF Seeds (formerly PGG Wrightson Seeds [Australia] Pty Ltd). 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 of two new sub clovers, following completion of Stage 2 field trials in WA, Victoria, New South Wales and New Zealand. Selection of sub clover breeding lines for low and medium rainfall areas also continued at Shenton Park Field Station. Two breeding populations of balansa clover were initiated at Shenton Park and Manjimup, while 70 purple clover (T. *purpureum*) wild populations were evaluated for their commercial merit, as part of William Tan's Masters project.

New PhD student Julian van der Zanden commenced working on a subterranean clover genetics project in September 2021. Current PhD student Gereltsetseg Enkhbat examined mechanisms for root plasticity affecting plant growth during drought, following a period of waterlogging, in contrasting genotypes of ssp. *yanninicum* sub clover (See: Chapter 3 Water for Food Production).

This research is supported by DLF Seeds.

Associate Professor Phillip Nichols screening ssp. *yanninicum* sub clover breeding lines for waterlogging.

Associate Professor Phillip Nichols and Senior Research Officer Brad Wintle presenting at the 2021 Shenton Park Research Facility Open Day.

Bee landing on a clover flower.

Bee Friendly Pastures: New opportunities for the production of premium and medicinal honey

Project team: Dr Kevin Foster[1,2] (project leader; kevin.foster@uwa.edu.au), Daniel Kidd[1], Dr Joanne Wisdom[1], Dr Kate Hammer[1], Associate Professor Cornelia Locher[1], Tiffane Bates[1], Dr Liz Barbour[2]

Collaborating organisations: [1]UWA; [2]Cooperative Research Centre for Honey Bee Products Ltd

Overseas, pasture species are recognised as a quality floral resource and an excellent source of crude protein: they would provide ideal supplementary sources for apiarists in Australia. Planting annual and perennial legume species can help restore previous levels of bee forage resources and offer pollinators a range of floral preferences. Clover honeys produced from various species of the genus *Trifolium* are considered a premium product worldwide. Many of the aerially seeding clover species bred in Australia (from Mediterranean origins) have flowers that are conspicuous to bees and provide easy access. For instance, crimson clover (*T. incarnatum*) is highly attractive to bees, has inflorescences high in the canopy and is a good source of pollen and nectar. Interest in planting for bees is also increasing in Australia, however our industry needs its own comprehensive list of bee friendly pastures.

The planting of more bee-friendly annual and perennial legume forages can help restore lost floral resources. Both farmers and beekeepers can gain opportunities to maximise land use and reduce costs by stacking these primary enterprises. These legume pastures importantly can also provide the industry with reliable sources each year by quantifying the timing of flowering and production of floral resources. Selecting a mix of legume species (both annual and perennial) with a wide range of maturity can also ensure floral continuity under variable conditions.

Developing different uses for apiary products could also assist the beekeeping industry in Australia. The demand for specialist pharmaceutical honey products is gaining momentum worldwide. Monofloral bioactive honeys are highly sought after and priced accordingly as seen in the growing global demand for specialist pharmaceutical honeys such as Manuka honey (*Leptospermum scoparium).* The use of honey from legumes as a therapeutic agent is an exciting prospect for the beekeeping industry. Honey contains various phenolic acids and flavonoids, which contribute to its bioactivity and potential pharmaceutical use. Flavonoids, for example, exhibit a wide range of biological effects, including antibacterial, anti-inflammatory, anti-allergic, antithrombotic, and vasodilatory actions.

In support of the call for more research on clover honeys, a new UWA PhD study by Sharmin Sultana has begun to assess a range of annual and perennial pasture legumes for suitability as a potential source of bioactive honeys. A recent literature review (Sultana *et al.* 2022) focused on the physicochemical characteristics, key phytochemical constituents and different bioactivities reported for clover honeys produced from various *Trifolium* spp. It concluded these should be further investigated to exploit new opportunities of potential benefit to both the pharmaceutical and apiculture industries.

This research was supported by AgriFutures Australia and the CRC for Honey Bee Products Ltd.

Dr Kevin Foster in a field of Persian clover.

BeefLinks Partnership Program

Project team: Professor Philip Vercoe[1] (project leader; philip.vercoe@uwa.edu.au), Dr Julian Hill[2], Naomi Leahy[3], Dr Margaret Jewel[3], Dr David Beatty[4]

Collaborating organisations: [1]UWA; [2]Ternes Agriculture; [3]MLA; [4]DPIRD; West Midland Group; Select Carbon, France; Rio Tinto

The BeefLinks Partnership Program has now been underway for two years. It is a collaborative research, development, extension and adoption (RDE&A) partnership involving MLA, UWA and Rio Tinto. The partnership also engages with the beef value chain through an industry steering committee. The vision of BeefLinks is to drive an integrated and complementary RDE&A program for northern and southern production systems across Western Australia to achieve profitable, consistent and sustainable beef yields matched to consumer expectations.

One of the main objectives of the research is to develop systems that improve both productivity and the environmental footprint of the northern WA beef industry, a critical component of the supply chain. BeefLinks has gained momentum as data comes in from the field, is analysed and disseminated to the BeefLinks group and industry. The number of contracted projects underway has now increased from five to eight, including:

- BeefLinks Coordination Project
- Growing WA backgrounding through adoption
- Accelerating the transition
- DietID – feedbase mapping to raise productivity of cattle
- Defining the potential and application of (native) Australian plants for a carbon neutral northern beef value chain in Western Australia ('CN30')
- BeefLinks: Management of cattle in the Australian rangelands using virtual fencing/herding technologies (Virtual Fencing)
- Pardoo PhD project: Beef production under irrigated systems
- Socio-economic project

New projects include PhD research that is set to get underway in the coming months at Pardoo station in the Pilbara region. At the heart of the project is animal welfare and production efficiencies specifically through gaining knowledge on cattle heat stress and feed base modifications. The Socio-economic project is now active and will help coordinate, monitor and evaluate the research and adoption activities both within each research project and across the BeefLinks program.

A website is being established for BeefLinks where we will post regular updates about the results from the projects as well as any other extension and engagement activities or opportunities.

This research is supported by UWA, MLA, and Rio Tinto.

BeefLinks team members Dr Lindsey Perry and UWA Dr Zoey Durmic collecting plant samples for laboratory analysis in the CN30 project.

BeefLinks team on a field trip to the Pilbara, WA. Dr Lindsey Perry (Beef Productivity Project Manager), Erin O'Brien (Backgrounding project), and UWA Dr Zoey Durmic (CN30, Virtual fencing, and DietID).

Comparative expression profiling and sequence characterisation of *ATP1A1* gene associated with heat tolerance in tropically adapted cattle

Project team: Dr Muhammed Elayadeth-Meethal[1,2,3] (project leader; muhammed@kvasu.ac.in), Dr Aravindakshan Thazhathu Veettil[2], Dr Muhasin Asaf[2], Sathiamoorthy Pramod[3], Professor Shane Maloney[1], Emeritus Professor Graeme Martin[1], Dr Jordana Rivero[4], Dr Veerasamy Sejian[5], Professor Punnoth Poonkuzhi Naseef[6], Dr Mohamed Saheer Kuruniyan[7], Professor Michael Lee[8]

Collaborating organisations: [1]UWA; [2]Kerala Veterinary and Animal Sciences University, India; [3]Livestock Research Station, Kerala, India; [4]Rothamsted Research, UK; [5]ICAR-National Institute of Animal Nutrition and Physiology, India; [6]King Khalid University, Saudi Arabia; [7]Moulana College of Pharmacy, India; [8]Harper Adams University, UK

Climate change is an imminent threat to livestock production. One adaptation strategy is selection for heat tolerance. While it is established that the *ATP1A1* gene and its product play an important role in the response to many stressors, there has been no attempt to characterise the sequence or to perform expression profiling of the gene in production animals.

We undertook a field experiment to compare the expression profiles of *ATP1A1* in heat-tolerant Vechur and Kasaragod cattle (*Bos taurus indicus*) with the profile of a heat-susceptible crossbreed (*B. t. taurus* × *B. t. indicus*). The cattle were exposed to heat stress while on pasture in the hot summer season. The environmental stress was quantified using the temperature humidity index (THI), while the heat tolerance of each breed was assessed using a heat tolerance coefficient (HTC).

The *ATP1A1* mRNA of Vechur cattle was amplified from cDNA and sequenced. The HTC varied significantly between the breeds and with time-of-day ($p < 0.01$). The breed–time-of-day interaction was also significant ($p < 0.01$). The relative expression of *ATP1A1* differed between heat-tolerant and heat-susceptible breeds ($p = 0.02$). The expression of *ATP1A1* at 08:00, 10:00 and 12:00, and the breed–time-of-day interaction, were not significant.

The nucleotide sequence of Vechur *ATP1A1* showed 99 per cent homology with the *B. t. taurus* sequence. The protein sequence showed 98 per cent homology with *B. t. taurus* cattle and with *B. grunniens* (yak) and 97.7 per cent homology with *Ovis aries* (sheep). A molecular clock analysis revealed evidence of divergent adaptive evolution of the *ATP1A1* gene favouring climate resilience in Vechur cattle.

These findings further our knowledge of the relationship between the *ATP1A1* gene and heat tolerance in phenotypically incongruent animals. We propose that *ATP1A1* could be used in marker assisted selection for heat tolerance.

This research is supported by UWA, the Crawford Fund, Kerala Veterinary and Animal Sciences University (India), Rothamsted International Fellowship, and Soil to Nutrition Institute Strategic Research Programme of Rothamsted Research (UK).

Vechur cow (dwarf *Bos taurus indicus*).

Citral and linalool reduce methane production through actions on rumen microbiota, specifically inhibiting methanogenic archaea

Project team: Muhammad Shoaib Khan[1], Dr Claus Christophersen[2], Dr Zoey Durmic[1], Emeritus Professor Graeme Martin[1], Professor Philip Vercoe[1] (project leader; phillip.vercoe@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]Curtin University; WA Human Microbiome Collaboration Centre

The global population is predicted to be around 10 billion by 2050 leading to increased demand for protein of animal origin and therefore efficient livestock production. However, livestock industries are responsible for about 12 per cent of national greenhouse gas emissions, so expanding these industries while avoiding deleterious effects on the environment is a major challenge. One option is to add natural compounds in livestock feed that will reduce methane production.

This project aimed to determine the mechanism of action of two essential oils, citral and linalool, that had been identified in two Australian native plants, *Melaleuca teretifolia* and *Melaleuca ericifolia*, that reduce methane production in the rumen. We studied the effects of the essential oils on rumen fermentation and the rumen microbial population, using rumen simulation in vitro.

Both compounds reduced methane production with far fewer adverse effects than the two well-known chemical inhibitors, chloroform and monensin (an antibiotic), during 24-hour fermentation in batch culture. To test whether these beneficial effects could be maintained over relevant time periods, we moved to a continuous culture system (RUSITEC) that mimics the sheep rumen. For three weeks, citral and linalool both reduced methane production while stimulating overall fermentation, as measured by total gas production.

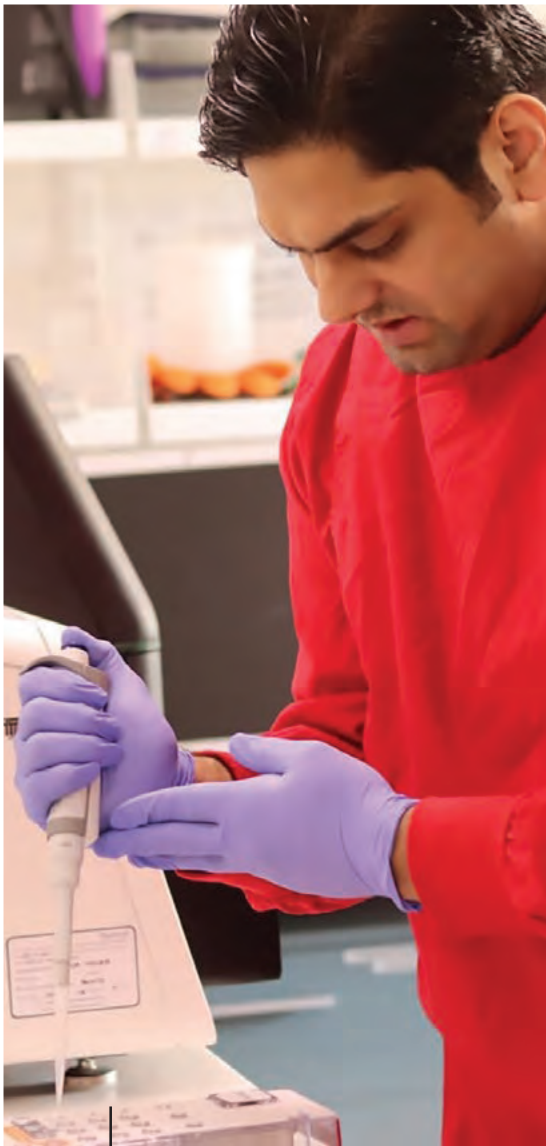
We studied the microbial population using a technique called 'targeted amplicon DNA sequencing'. The results showed that both compounds affected the diversity and richness of the bacterial population and were better than monensin. We also studied effects on the number of bacteria in the rumen by quantifying the copies of bacteria genes, and found no differences among citral, linalool and monensin. This means that the essential oils caused a dynamic shift in the structure of the bacterial population without reducing the total numbers of bacteria.

By integrating DNA sequencing data with metabolomics, using a newly developed pipeline, we linked the bacterial population with fermentation end-products (e.g. volatile fatty acids; VFA) that act as a source of energy. This was the first time this kind of analysis had been done in rumen microbiology and it enhanced our understanding of the factors that determine the relationship between VFA and changes in bacterial populations.

Finally, we investigated the effects of citral, linalool and monensin on the rumen population of archaea, the microbes that produce methane. Both essential oils used a mechanism of action to inhibit archaea that differed from the mechanism used by monensin.

In conclusion, we now have a sound scientific foundation for testing the essential oils, citral and linalool in animal experiments, with a view to extending the concept to grazing systems to reduce the carbon footprint of the livestock industries.

This research is supported by the UWA-UAF Scholarship, scholarship for International Research Fees, Ad Hoc Postgraduate Scholarship, and Underwood PhD Completion Scholarship.



Muhammad Shaoib Khan preparing archaeal DNA library for sequencing on Miseq.

Impact of the COVID-19 pandemic on the welfare of animals in Australia

A major welfare concern for intensive livestock industries, such as pork and chicken meat production, was the risk of disruption to the supply chain if personnel contracted the virus.

Project team: Jacqueline Baptista[2], Associate Professor Dominique Blache[1,3], Dr Keren Cox-Witton[4], Nicola Craddock[5], Dr Toni Dalziel[6], Nicolas de Graaff[5], Dr Jill Fernandes[3], Dr Ronda Green[7], Helen Jenkins[8], Dr Sarah Kahn[9], Deborah Kelly[6], Dr Mariko Lauber[10], Professor Shane Maloney[1], Bridget Peachey[11], Ian Rodger[12], Jeremy Skuse[13], Professor Alan Tilbook[3] (project leader; a.tilbrook@uq.edu.au), Frederick Professor Rohan Walker[3,14], Kelly Wall[8], Dr Sarah Zito[15]

Collaborating organisations: [1]UWA; [2]JB Consulting, Australia; [3]University of Queensland; [4]Wildlife Health Australia; [5]Zoo and Aquarium Association; [6]Department for Environment and Water, Government of South Australia; [7]Wildlife Tourism Australia; [8]Animal Health Australia; [9]DPIRD; [10]Greyhound Racing Victoria; [11]Australian Wool Innovation Limited; [12]Department of Agriculture and Fisheries, Queensland Government; [13]Animal Welfare Connections; [14]The University of Newcastle;[15]RSPCA Australia

This research reports on the various responses in Australia during 2020 to minimise negative impacts of the COVID-19 pandemic on the welfare of animals. Most organisations and individuals with animals under their care had emergency preparedness plans in place for various scenarios; however, the restrictions on human movement to contain the spread of COVID-19, coupled with the economic impact and the health effects of COVID-19 on the skilled workforce, constituted a new threat to animal welfare for which there was no blueprint.

The spontaneous formation of a national, multisectoral response group on animal welfare, consisting of more than 34 organisations with animals under their care, facilitated information flow during the crisis, which helped to mitigate some of the shocks to different organisations and to ensure continuity of care for animals during the pandemic.

We concluded that animal welfare is a shared responsibility, and accordingly, a multisectoral approach to animal welfare during a crisis is required. Our experience demonstrates that to safeguard animal welfare during crises, nations should consider the following: a national risk assessment, clear communication channels, contingency plans for animal welfare, a crisis response group, and support systems for animal care providers. Our findings and recommendations from the Australian context may inform other countries to ensure that animal welfare is not compromised during the course of unpredictable events.

The methane intensity of kangaroo meat compares favourably to ruminant meats: a pathway to reduced agricultural emissions

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

Collaborating organisation: [1]UWA

Despite the importance of reducing greenhouse gas (GHG) emissions, Australia's agricultural emissions in 2030 are projected to be similar to those of 1990. This raises the question as to whether enough has been done to tackle agriculture's GHG footprint or whether more radical, transformative approaches are required.

One of the potential pathways to reduce agricultural emissions is the substitution of a proportion of ruminant meat with non-ruminant meat, including native macropod meat which, as foregut fermenters, produce negligible amounts of methane in comparison to ruminants. However, as kangaroo methane emissions have not been comprehensively evaluated in the context of species-specific growth rates and carcase attributes, it is not possible to make accurate comparisons with sheepmeat or beef.

In this paper, we collated a series of industry data points on the drivers of variation in methane intensity and developed a series of equations to identify the methane intensity of kangaroo meat (expressed in kg CO_2-e/kg product) from the species commercially harvested in Western Australia. We then compared kangaroo meat to sheepmeat and beef and consider the potential to reduce the state's agricultural emissions by substituting kangaroo meat, available under current harvest quotas, for an equivalent quantity of sheepmeat or beef.

Our results demonstrate that kangaroo meat has an average methane intensity of 3.6 kg CO_2-e/kg product, approximately 80 per cent lower than sheepmeat and 88 per cent lower than beef, with a range of 2.3 – 4.0 kg CO_2-e/kg product depending on the species and gender of the harvested animal.

Increasing the harvest of kangaroos in Western Australia to current maximum harvest quotas would yield an additional 9000 tonnes of meat annually. Reducing sheepmeat production by 9000 tonnes would reduce methane emissions attributable to the state's sheepmeat sector by 4.8 per cent. Alternatively, reducing beef production by 9000 tonnes would reduce methane emissions attributable to the state's cattle sector by 6.5 per cent. If this reduction is split evenly between the two sectors (4500 tonnes each) this would reduce the state's net agricultural emissions by 1.8 per cent.

Our results have particular relevance from a comparative perspective as kangaroos are one of the few other options for producing high value products (protein and leather) from low quality forages in extensive regions that are unsuitable for most other forms of agriculture.

This research is supported by UWA.

A group of grey kangaroos in the bush.

PhD candidate Isobel Sewell with a barramundi at the conclusion of a three-month growth trial.

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. The aim of this research will be 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).

The findings from this research, so far, suggest that BSFL is a viable alternative protein source.

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.

Marron at the commencement of a three-month growth trial at the UWA Shenton Park Field Station Aquaculture Facility.

Living Streams Aquaculture

Project team: Professor Philip Vercoe[1], Dr Craig Lawrence[1] (project leader; craig.lawrence@uwa.edu.au), Isobel Sewell[1], Steve Palmer[2]

Collaborating organisations: [1]UWA; [2]Greenvale Enterprises Pty Ltd – Palmer Group

In 2021 we commenced a collaborative research project between an industry partner and UWA to:

- Develop a green energy aquaculture production system, and
- Provide a better environment for growing aquaculture species such as marron.

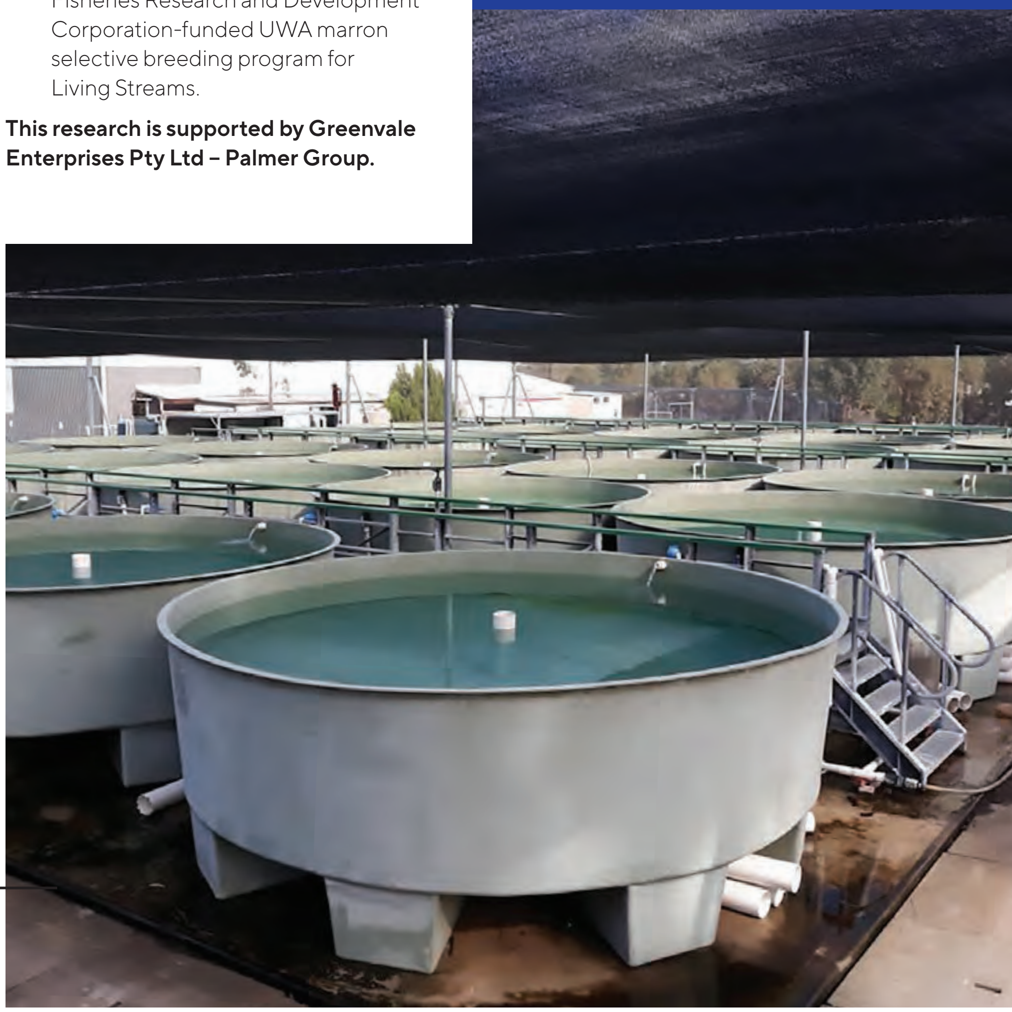
Living streams is a production system designed to rear aquaculture species such as marron in clean, flowing water, simulating that of a natural stream environment. Unlike many aquaculture systems it is non-polluting, with water being constantly filtered and reused in the system, consequently it does not release any effluent into the environment. Green energy (solar, geothermal & hydrogen) is used to operate the system, including maintaining optimum flow rates, water temperatures and oxygen levels.

Our research at the UWA Shenton Park Field Station will address three areas:

- Living Streams Engineering Progra
  - System design and construction including green energy power supply (solar & hydrogen production), temperature control (geothermal), water filtration & water quality management, provision of optimum flow rates, increased aeration and O2 injection, shelter design, automated system monitoring and data logging.
- Nutrition Progra
  - Develop a nutritionally complete diet based upon terrestrial protein, lipids and attractants to replace marine fish meal and fish oil in the diet of farmed crustaceans
- Breeding Progra
  - Re-establish our previously successful Fisheries Research and Development Corporation-funded UWA marron selective breeding program for Living Streams.

This research is supported by Greenvale Enterprises Pty Ltd – Palmer Group.

Hatchery and nutrition research tanks at UWA Aquaculture Laboratory, Shenton Park Field Station.



Growout research tanks UWA Aquaculture Facility, Shenton Park Field Station.

Sunrise over a farm dam in rural Australia.

3

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 twenty 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 rainfed agriculture.

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

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

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

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

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Logging roads in East Kalimantan.

Deforestation-induced surface warming is influenced by the fragmentation and spatial extent of forest loss in Maritime Southeast Asia

Project team: Dr Octavia Crompton[1,3] (project leader; octavia@berkeley.edu), Débora Corre[1,2], Dr John Duncan[1], Associate Professor Sally Thompson[1]

Collaborating organisations: [1]UWA; [2]ARC Industrial Transformation Training Centre; [3]University of California, Berkeley

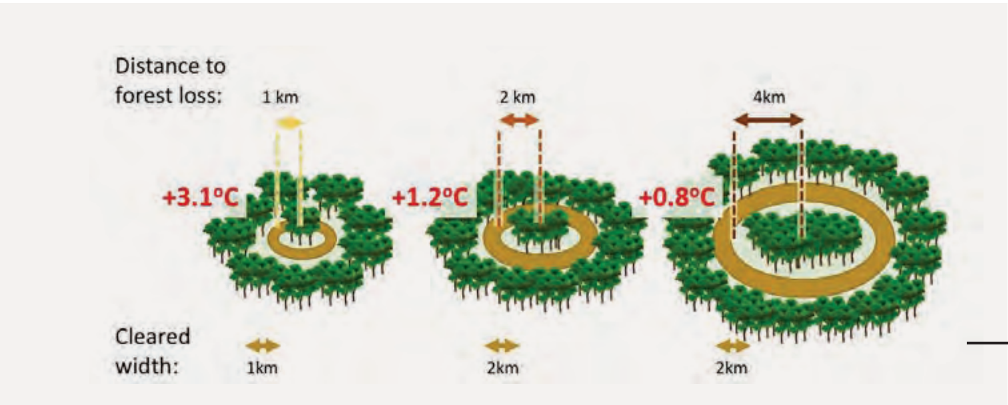
This research used satellite imagery to find ways to avoid the worst-possible temperature increases in Southeast Asian countries due to deforestation. UWA researchers built a web mapping tool to explore the effects of different patterns and areas of forest loss on local temperatures in Southeast Asia.

Southeast Asian countries have rapidly lost their tropical forests in recent decades due to expanding palm oil and timber plantations, logging, mining and the establishment of small-scale farms. Forests cool the climate directly as a result of trees drawing water from the soil to their leaves through transpiration. The energy needed to evaporate the water is taken from the air – the same reason you feel colder when you get out of a pool with water on your skin. A single tree could cause local surface cooling equivalent to 70kWh for every 100 litres, which is as much cooling as two household air conditioners. From this study, we found that tropical forests are also cooling for themselves and their neighbourhood – giving us another reason to value and conserve tree cover in our warming world.

In tropical areas, rapid forest loss accounted for up to 75 per cent of the observed surface warming between 1950 and 2010. When forests in tropical regions are cut down, the evaporative cooling stops – and this land surface warming is large enough that it can be detected from space using satellite data. The researchers used satellite imaging to focus on places that had not yet been affected by forest loss and discovered that the removal of forests up to 6km away was causing warming in those areas. If you completely cut down all the forest in a ring 2-to-4km wide, the land surface in the middle of the ring would warm up by an average of 1.2°C. The closer the forest loss, the higher the warming, so if the ring was 1-to-2km away it would be 3.1°C, but at 4-to-6km away, it's 0.75°C.

If forests must be removed, the study determined ways to avoid the worst-case scenario increases in temperature. It found that warming after forest removal was reduced if at least 10 per cent of the original forest cover was retained. Similarly, temperatures did not increase as much when the area of forest loss was smaller. If forest removal affects the landscape in smaller, discontinuous blocks rather than uniformly, the temperature increases will be less severe. Significant economic benefits (in terms of agricultural productivity and human health) directly connected to conserving forests.

This research is supported by the National Geographic Society and its AI for Earth Grant program funded by Microsoft.



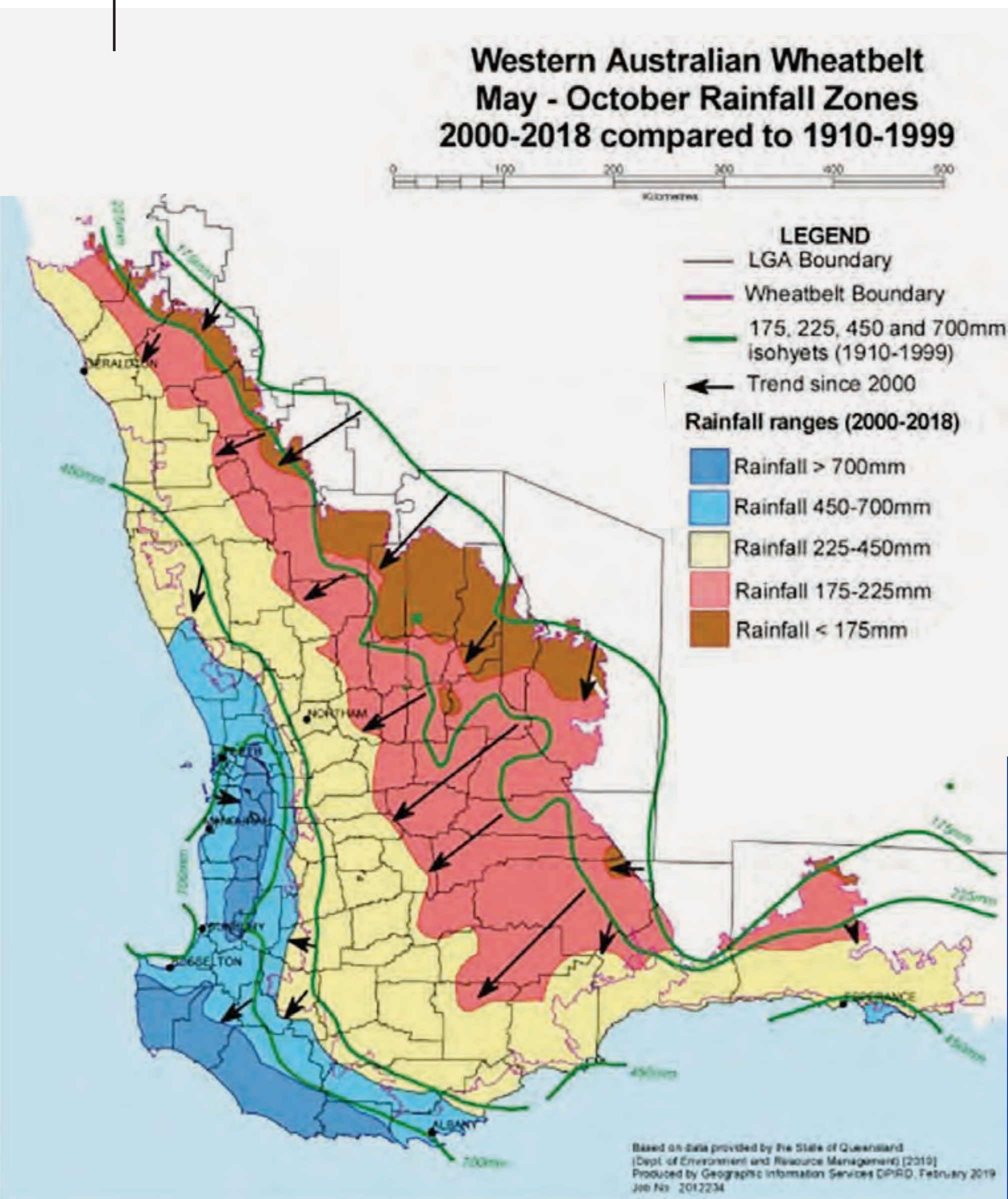
This diagram shows how the researchers measured the effects of forest loss (the brown rings) on the increase in temperature.

A review of surface enhanced experimental catchments to improve farm water security and resilience in a drying climate in southwestern Australia

Project team: Professor Neil Coles[1] (project leader; neil.coles@uwa.edu.au), David Stanton, Dr Chun Woo Baek[2]

Collaborating organisations: [1]UWA; [2]Korean Reinsurance Company, South Korea

Rainfall shifts in the May to October growing season period for south-west Western Australia.



For this research, the evolution of runoff enhancement treatments on both natural and artificial (or roaded) catchments used for rainfall harvesting to supply small on-farm dams in south-western Australia is reviewed.

Over the last seven decades, various experimental treatments and approaches to enhance water shedding or harvesting techniques have been tested and adapted across this region to account for variations in slope, soil type and rainfall distribution. These adaptations are vital to maintain water harvesting efficiency and water security in a drying climate and enable farmers to continue to produce crops and support livestock effectively while increasing their climate resilience.

As such, water security is one of the most important components of any agricultural enterprise. The treatments or sealants evaluated, varied in their capacity, cost, durability or water shedding capability, to provide a robust response to changes experienced in rainfall patterns, their intensity and frequency due to climate change. This review highlighted the potential to use various surface treatments to increase the water harvesting efficiency from different landscapes in semi-arid or dryland agricultural areas in southwestern Australia.

The impact of soil water repellency and slope upon runoff and erosion

Project team: Dr Mary-Anne Lowe[1], Gavan McGrath[1,2], Associate Professor Matthias Leopold[1] (project leader; matthias.leopold@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]Department of Biodiversity, Conservation and Attractions, WA

Soil water repellency (SWR) increases the amount of runoff and erosion from soils. Previous experiments on water-repellent soils had shown intricate runoff movement and high rates of water and soil losses; our aim was to observe these processes, noting their influences and quantifying impacts.

The experiment used a 60 × 60 cm rainfall simulation plot setup to represent an agricultural plot with packed water repellent soil and no interference of plants. We measured inputs, and monitored surface flows and erosion on 3°, 6° and 9° slopes. A surfactant treated plot was used as a control. Eroded sediment samples were collected and measured for particle size, and together with runoff analysed for organic carbon, nitrogen and macronutrients. Runoff coefficients were high (0.53 to 0.78) for untreated soil with erosion decreasing over the course of the experiment (1.41 t ha-1 to 0.74 t ha-1 over five 2mm rainfall events, of two-minute duration, on the 9° slope). This resulted in cumulative erosion of up to 5.35 t ha-1 after a total of 10mm of rainfall (5 × 2 mm). Importantly, silt and clay were preferentially eroded (up to 12 times higher in eroded soil than the baseline composition) and this correlated with the loss of organic carbon, nitrogen, and macronutrients.

As expected, the steepest slope (9°) caused greater runoff and erosion than the lowest (3°), however, there was no significant difference in runoff and erosion between the 6° and 9° slope. Surfactant significantly decreased runoff coefficients by two orders of magnitude compared to the untreated soil. Surface flow was initially characterised by beading and rivulet formation, minimising soil contact.

Over time, however, a perched, protective water layer formed over the surface, allowing subsequent water flow with reduced soil interaction. The runoff mechanisms for these small rain events were only observed on the water-repellent soils and likely reduced the degree of erosion given the high runoff coefficients. Initial water flow also promoted armouring of the soil by the attraction of smaller particles, leading to increased loss of organic carbon and nitrogen as well as macronutrients.

This research is supported by UWA, DPIRD and the CRC for Polymers.

Progression through time showing movement of water across the surface leaving dry soil below and carrying soil particles on the outside of the water body. White point is a surface position marker, white lines and arrows show the waterfront moving as it moves across the surface. Photos taken in sequence on the 6° slope with untreated soil on the first rainfall event.

Quasi 3D soil moisture distribution using electromagnetic induction and buried soil sensors

Project team: Associate Professor Matthias Leopold[1] (project leader; matthias.leopold@uwa.edu.au), Associate Professor Ken Flower[1], Hira Shaukat[1]

Collaborating organisation: [1]UWA

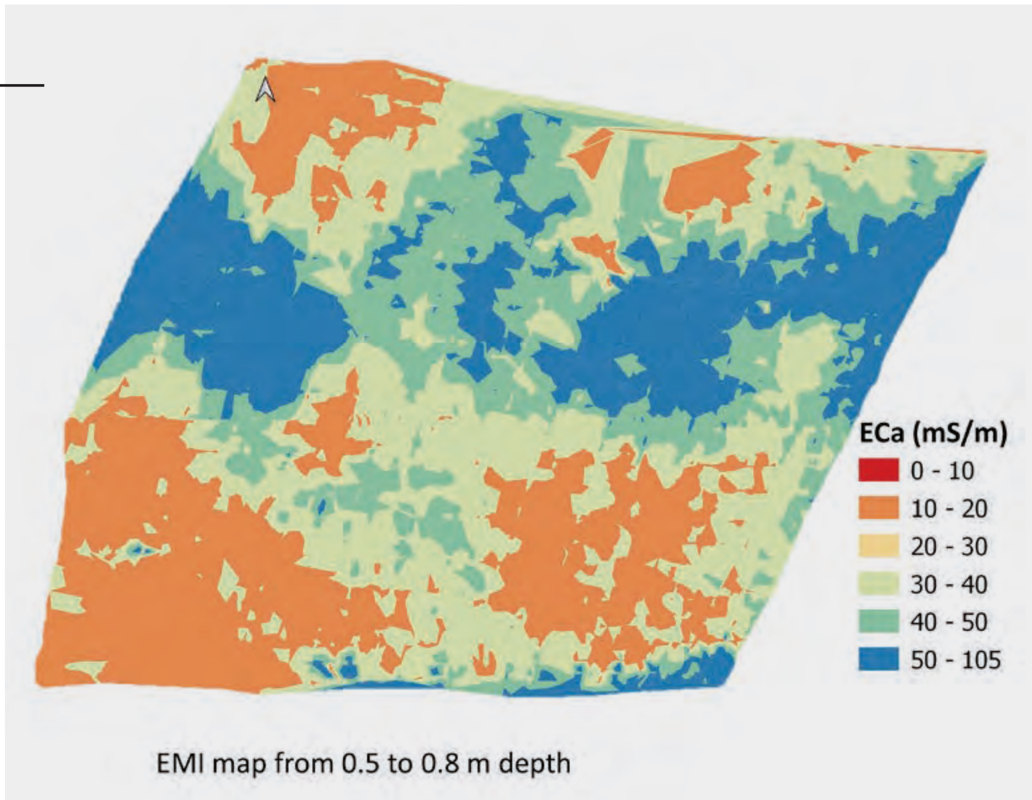
Knowledge of real time spatial distribution of soil moisture has great potential to improve yield and profit in agricultural systems. Recent advances in non-invasive electromagnetic induction (EMI) techniques have created an opportunity to determine soil moisture content with high-resolution and minimal soil intrusion. So far, EMI has mainly been used for homogenous soil conditions, which are not common in agriculture and results are mainly validated by excavated pits or calibration models using soil samples on a transect.

UWA PhD candidate Hira Shaukat used EMI technology to study the soil moisture at the Watts 2 paddock in Western Australia. The paddock represents a complex pattern of soils which differ in their horizontal and vertical distribution of soil properties. The work combines EMI techniques and classic 1D moisture probes, to provide soil moisture maps for the dry and wet season.

This research is supported by UWA, the RTPFI – RTP International Fees Offset, and University Postgraduate Award (International Students).

PhD candidate Hira Shaukat with the EMI device on a sled.

An EMI map for the Watts 2 paddock.



‘Omics’ approaches in developing combined drought and heat tolerance in food crops

Project team: Anjali Bhardwaj[2], Poonam Devi[2], Shikha Chaudhary[2], Anju Rani[2], Dr Uday Chand Jha[3], Dr Shiv Kumar[4], Dr H Bindumadhava[5], Dr P V Vara Prasad[6], Professor Kamal Dev Sharma[7], Hackett Professor Kadambot Siddique[1], Professor Harsh Nayyar[2] (project leader; harshnayyar@hotmail.com)

Collaborating organisations: [1]UWA; [2]Panjab University, India; [3]Indian Institute of Pulses Research, India; [4]ICARDA, Morocco; [5]Dr. Marri Channa Reddy Foundation, India; [6]Kansas State University, UWA; [7]CSK H.P. Agricultural University, India

Global climate change will significantly increase the intensity and frequency of hot, dry days. The simultaneous occurrence of drought and heat stress is also likely to increase, influencing various agronomic characteristics, such as biomass and other growth traits, phenology, and yield-contributing traits, of various crops. At the same time, vital physiological traits will be seriously disrupted, including leaf water content, canopy temperature depression, membrane stability, photosynthesis, and related attributes such as chlorophyll content, stomatal conductance, and chlorophyll fluorescence. Several metabolic processes contributing to general growth and development will be restricted, along with the production of reactive oxygen species (ROS) that negatively affect cellular homeostasis.

Plants have adaptive defence strategies, such as ROS-scavenging mechanisms, osmolyte production, secondary metabolite modulation, and different phytohormones, which can help distinguish tolerant crop genotypes. Understanding plant responses to combined drought/heat stress at various organizational levels is vital for developing stress-resilient crops. Elucidating the genomic, proteomic, and metabolic responses of various crops, particularly tolerant genotypes, to identify tolerance mechanisms will markedly enhance the continuing efforts to introduce combined drought/heat stress tolerance. Besides agronomic management, genetic engineering and molecular breeding approaches have great potential in this direction.

This research is supported by UWA, the Department of Science & Technology, University Grants Commission, Department of Biotechnology, ICARDA (Morocco), IIPR (Kanpur), PAU (Ludhiana), and the World Vegetable Center.

Rows of sorghum crop suffering from the effects of drought.

Watershed drought and ecosystem services: Spatiotemporal characteristics and gray relational analysis

Project team: Jizhou Bai[2], Dr Zixiang Zhou[2], Adjunct Associate Professor Yufeng Zou[1,3,4] (project leader; zouyufeng@nwafu.edu.cn), Dr Bakhtiyor Pulatov[4], Hackett Professor Kadambot Siddique[1]

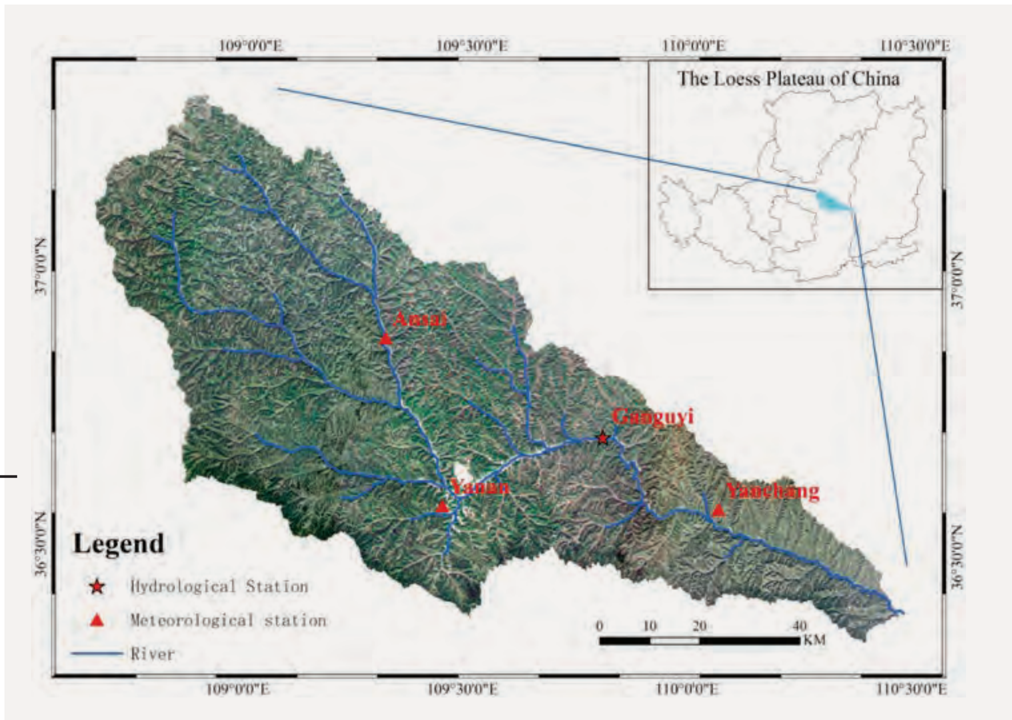
Collaborating organisations: [1]UWA; [2]Xi'an University of Science and Technology, China; [3]Northwest A&F University, China; [4]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Uzbekistan

This study explored the spatiotemporal characteristics of drought and ecosystem services (using soil conservation services as an example) in the YanHe Watershed, which is a typical water basin in the Loess Plateau of China, experiencing soil erosion. Herein, soil conservation was simulated using the Soil and Water Assessment Tool (SWAT), and the relationship between drought, soil conservation services, and meteorological, vegetation, and other factors since the implementation of the 'Grain for Green' Project (GFGP) in 1999, were analysed using the gray relational analysis (GRA) method. The results showed that:

- The vegetation cover of the Watershed has increased significantly, and evapotranspiration (ET) increased by 14.35 mm·a–1, thereby increasing water consumption by 8.997 × 108 m3·a–1 (compared to 2000).
- Drought affected 63.86 per cent of the watershed area, gradually worsening from south to north; it decreased in certain middle areas but increased in the humid areas on the southern edge.
- The watershed soil conservation services, measured by the soil conservation modulus (SCM), increased steadily from 116.87 t·ha–1·a–1 in 2000 to 412.58 t·ha–1·a–1 in 2015, at a multi-year average of 235.69 t·ha–1·a–1, and indicated great spatial variations, with a large variation in the downstream and small variations in the upstream and midstream areas.
- Integrating normalised difference vegetation index (NDVI) data into SWAT model improved the model simulation accuracy; during the calibration period, the coefficient of determination (R2) increased from 0.63 to 0.76 and Nash–Sutcliffe efficiency (NSE) from 0.46 to 0.51; and during the validation period, the R2 increased from 0.82 to 0.93 and the NSE from 0.57 to 0.61.
- GRA can be applied to gray control systems, such as the ecosystem; herein, vegetation cover and drought primarily affected ET and soil conservation services. The analysis results showed that vegetation restoration enhanced the soil conservation services, but increased ET and aggravated drought to a certain extent.

This study analysed the spatiotemporal variations in vegetation coverage and the response of ET to vegetation restoration in the YanHe Watershed, to verify the significant role of vegetation restoration in restraining soil erosion and evaluate the extent of water resource consumption due to ET in the semi-arid and semi-humid Loess-area basin during the GFGP period. Thus, this approach may effectively provide a scientific basis for evaluating the ecological effects of the GFGP and formulating policies to identify the impact of human ecological restoration on ecosystem services.

This research is supported by the National Natural Science Foundation of China, Shaanxi Provincial Natural Science Basic Research Program, National Natural Science Foundation of China International (Regional) Cooperation and Exchange Project, and Xi'an University of Science and Technology PhD Startup Fund.



The YanHe Watershed in the Loess Plateau of China.

Reduced groundwater use and increased grain production by optimised irrigation scheduling in winter wheat–summer maize double cropping system – A 16-year field study in North China Plain

Project team: Dr Xiaolin Yang[2,3], Dr Guangya Wang[2], Dr Yuanquan Chen[2] (project leader; rardc@163.com), Dr Peng Sui[2], Steven Pacenk[3], Professor Tammo Steenhuis[4], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]China Agricultural University, China; [3]Cornell University, USA

Optimising irrigation strategies to increase water utilization efficiency and achieve higher yield is vital for balancing groundwater use and improving food security during water shortage in the North China Plain (NCP).

Based on a 16-year field experiment (2003–2018) using seven irrigation schedules from W0M0 to W4M3 (numbers are irrigation times in wheat (W) and maize (M) season, 75mm each) in the winter wheat–summer maize double cropping system, we analysed annual total water consumption (ETa) and groundwater table change in terms of net groundwater depletion, annual total grain yield, water productivity (WP), irrigation water productivity (IWP) and marginal benefit of the whole wheat–maize system. Relationship between yield or WP and irrigation or ETa were also revealed.

Results showed that:

- Total ETa increased as irrigation input increased, ranging from 427.3mm (Rainfed, W0M0) to 891.0mm (W4M3). Soil water storage contributed nearly 30 per cent to ETa for winter wheat under water deficit conditions. Pre-sowing soil water storage played an important role in improving the annual yield and WP of both wheat and maize by promoting germination, seedling emergence and root growth.
- The rainfed treatment (W0M0) was best for mitigating the groundwater table decline (0.1m yr-1), followed by W1M1 (0.5m yr-1) and W2M1 (0.8m yr-1). Groundwater table decline in M2W2 almost overlapped the observed data at the station (1.1 m yr-1). In W3M2, the farmers' traditional practice, the groundwater table declined by 1.4m yr-1, obviously over exploitation, while W4M2 and W4M3 declined by almost 2m yr-1.
- The relationship between total annual yield and irrigation (or ETa) followed a quadratic curve. Total annual yield significantly increased from W0M0 to M1W1 (25 per cent) to M2M1 (five per cent) and then kept stable. Average annual WP decreased as irrigation increased, from 2.4kg m-3 (W0M0) to 1.6kg m-3 (W4M3). Average annual IWP and marginal benefit also declined as irrigation increased.

These results over 16 years indicated that the W2M1 is the most balanced irrigation regime for wheat– maize rotation to mitigate groundwater decline, maintain grain production, and improve water use efficiency in the NCP.

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

Corn fields in the North China Plain.

Wheat cultivars with small root length density in the topsoil increased post-anthesis water use and grain yield in the semi-arid region on the Loess Plateau

Project team: Yan Fang[2,3], Liyan Liang[2,3], Shuo Liu[2,3], Professor Bingcheng Xu[2,3], Hackett Professor Kadambot Siddique[1], Dr Jairo Palta[1,4], Dr Yinglong Chen[1,2,3] (project leader; yinglong.chen@uwa.edu.au)

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

Large distribution of roots in topsoil layers allow more uptake of soil water and nutrients during the vegetative growth, but it may be disadvantageous if soil water deficit develops during the reproductive stage.

The relationship between the distribution of roots in topsoil (0–0.4m) and soil water use, dry matter and nitrogen (N) accumulations, and grain yield was examined in winter wheat (*Triticum aestivum* L.) with contrasting root size in the topsoil. Two old landraces (CW134 and JM47, larger root length and biomass in the topsoil) and two modern wheat cultivars (CH58 and LH7, smaller root system size in the topsoil), were grown in the field during two seasons (2016–2017 and 2017–2018) under rainfed and irrigation conditions in the semi-arid farmland on the Loess Plateau. Root biomass and root length density (RLD) in topsoil (0–0.4m) was significantly higher in the old landraces than in the modern cultivars ($P < 0.05$) under rainfed and irrigation in both seasons (no such difference in subsoil, 0.4–1m).

The modern cultivars had significantly higher grain yield, grain N concentration, water-use efficiency (WUE), and 1000-grain weight ($P < 0.05$). Seasonal water use was similar among all cultivars, but post-anthesis water use was higher in the modern cultivars, particularly under rainfed conditions in both seasons. Root biomass and RLD in the topsoil was positively correlated with pre-anthesis water use, but negatively correlated with after anthesis water use. Post-anthesis water use was closely related to post-anthesis dry matter, N accumulation, yield and WUE under rainfed conditions.

To conclude, large distribution of roots in the topsoil had non-advantage for wheat grown under rainfed conditions. The small distribution of roots in the topsoil (characteristics of modern wheat cultivars) enhanced post-anthesis water use, increased post-anthesis dry matter and N accumulation, and hence attained higher grain yield and grain N when grown in the semi-arid environment.

This research is supported by the National Natural Science Foundation of China, China Postdoctoral Science Foundation Funded Project, Chinese Academy of Sciences, Shaanxi Postdoctoral Research Funding Project, and Natural Science Basic Research Program of Shanxi.

A close-up image of wheat roots growing in soil.

Large variation in waterlogging tolerance and recovery among the three subspecies of *Trifolium subterranean* L. is related to root and shoot responses

Project team: Gereltsetseg Enkhbat[1] (project leader; gereltsetseg.enkhbat@research.uwa.edu.au), Professor Megan Ryan[1], Dr Kevin Foster[1], Associate Professor Phillip Nichols[1], Dr Lukasz Kotula[1], Dr Ann Hamblin[1], Associate Professor Yoshiaki Inukai[2], Professor William Erskine[1]

Collaborating organisations: [1]UWA; [2]Nagoya University, Japan

Tolerance to waterlogging and recovery ability was compared among the three subspecies of subterranean clover (*Trifolium subterraneum* L.) to identify tolerance mechanisms, in order to guide future subclover breeding activities.

Three cultivars each of ssp. *yanninicum*, *subterraneum* and *brachycalycinum* were grown in a controlled environment glasshouse with *T. michelianum* as a waterlogging-tolerant control. After 28 days of growth two treatments were imposed for 35 days: free-draining (control) and waterlogged. A 21-day recovery period followed.

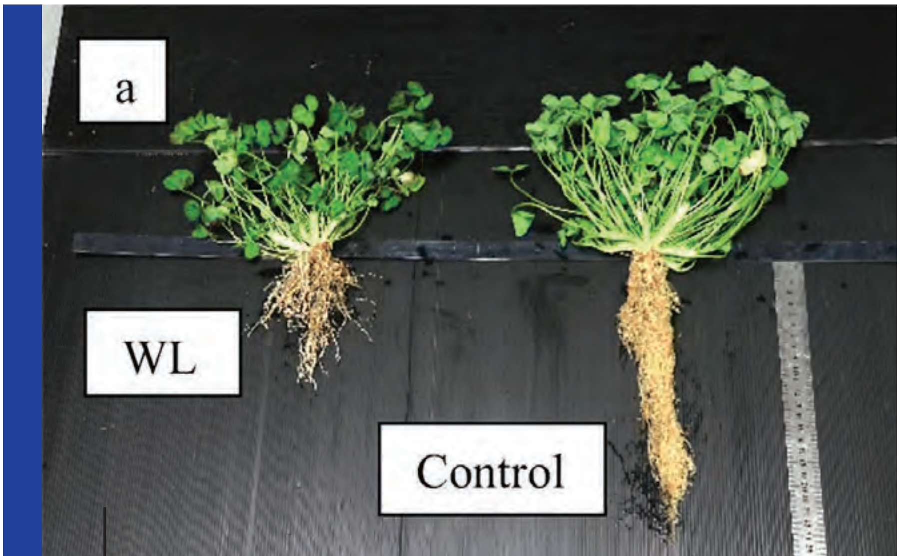
After 35 days, waterlogging reduced shoot dry weight (DW) to 58–27 per cent and root DW to 35–21 per cent of respective controls in each subspecies. Shoot relative growth rate (RGR) of *yanninicum* was least affected (78–104 per cent of control), compared to *subterraneum* (51–100 per cent) and *brachycalycinum* (45–69 per cent). The *subterraneum* cv. Denmark had a similar response to subspecies *yanninicum*. Shoot RGR of *T. michelianum* was 138 per cent of its control. After recovery, all traits (except tap root length) recovered to control values. Up to 21 days, the main traits associated with waterlogging tolerance (shoot and root growth) were high petiole length, less petiole anthocyanin pigmentation and high leaf chlorophyll content, but by 35 days these were a high proportion of leaf biomass, high stomatal conductance and enhanced root porosity.

Average root diameter and nodulation rates were unrelated to waterlogging tolerance.

Subspecies *yanninicum* had superior waterlogging tolerance. Priority traits for easily assessed indicators of waterlogging tolerance are less reduction of leaf size and high stomatal conductance.

This PhD research is conducted as part of Annual Legume Breeding Australia, which is a joint venture between UWA and the pasture seed company DLF Seeds (formerly PGG Wrightson Seeds [Australia] Pty Ltd).

This research is supported by the RTP Scholarship and Science Industry PhD Fellowship from the WA Government.



Trifolium subterraneum ssp. yanninicum cv. Meteora growth: (a) root comparison under waterlogged (WL) and control conditions; and (b) surface roots under WL conditions.

Impacts of land use conversion on the response of soil respiration to precipitation in drylands: A case study with four-yearlong observations

Project team: Dr Wenhao Sun[2], Professor Xining Zhao[2] (project leader; zxn@nwafu.edu.cn), Professor Xiaodong Gao[2,4], Dr Weiyu Shi[4], Professor Qiang Ling[2], Hackett Professor Kadambot Siddique[1]

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

Soil respiration (Rs) in drylands is strongly influenced by precipitation. However, there is a lack of long-term studies on how land-use conversion impact the Rs's responds to precipitation variations.

In situ Rs, soil moisture and soil temperature were monitored in cropland, and cropland converted jujube orchard, grassland and shrubland in the semiarid Loess Plateau, China for four years with significant interannual precipitation variation. Q10-soil moisture relationships were quantified by selecting observations within limited range of soil moisture. As soil moisture increased, Rs was found to be markedly suppressed in cropland and jujube orchard with great disturbance, with volumetric water content exceeding 0.15 and 0.16, respectively, but increased in grassland and shrubland with few disturbances. Q10 became saturated as soil moisture increased in cropland and was linearly correlated with soil moisture in jujube orchard, grassland and shrubland. Q10 was least sensitive to soil moisture variation in shrubland, which was characterized by a nitrogen-fixing shrub. The interannual variation in mean growing season Rs (MGR) was positively correlated with mean soil moisture. The difference in MGR between land-use types was significant except during the extreme drought year: converting cropland to jujube orchard saw a reduction in MGR by 5–18 per cent, while converting cropland to grassland and shrubland saw an increase in MGR by 16–53 per cent and 67–126 per cent, respectively. This corresponded with a greater sensitivity of MGR to soil moisture in grassland and shrubland.

These results suggest a greater response of soil carbon emission in the land-use applied with afforestation or restoration to the enhanced soil moisture as precipitation intensify, compared to agricultural land-use.

This research is supported by National Key Research and Development Program, National Natural Science Foundation of China, Natural Science Funds for Distinguished Young Scholar of Shaanxi Province, Shaanxi Innovative Research Team for Key Science and Technology, and 111 Project.

Terraced fields and spring mustard crops in the Loess Plateau, China.

The roots of a mature spring maize plant in the field.

Limited irrigation and fertilisation in sand-layered soil increases nitrogen use efficiency and economic benefits under film mulched ridge-furrow irrigation in arid areas

Project team: Cheng Li[2], Dr Hao Feng[2], Xiaoqi Luo[2], Yue Li[2], Naijiang Wang[2], Dr Wenjie Wu[2], Associate Professor Tibin Zhang[2], Dr Qin'ge Dong[2] (project leader; qgdong2011@163.com) Hackett Professor Kadambot Siddique[1]

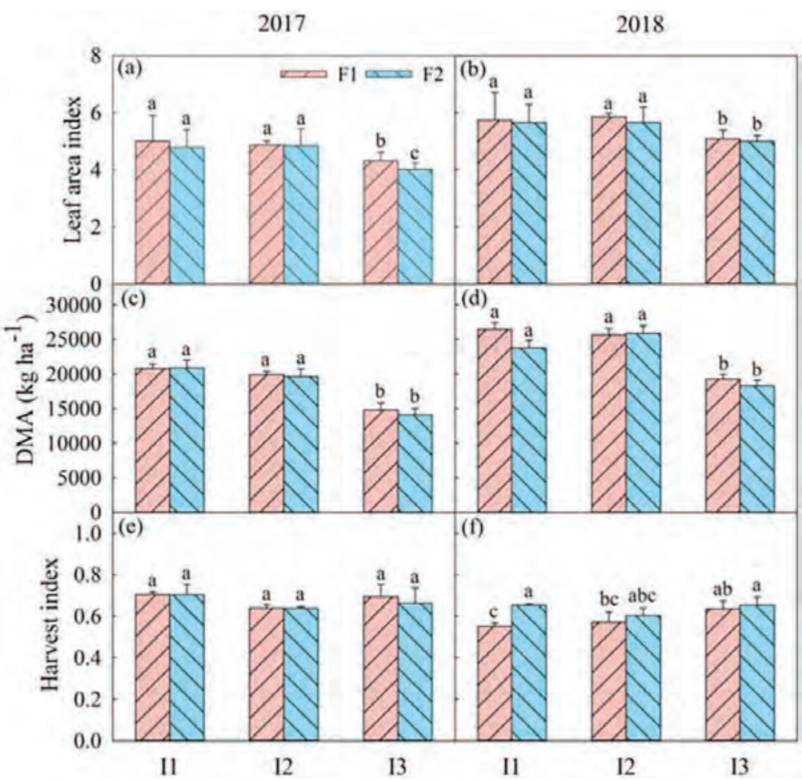
Collaborating organisations: [1]UWA; [2]Northwest A&F University, China

Hetao Irrigation District (HID) in the upper Yellow River Basin of China is vulnerable due to the scarcity of water resources and environmental pollution caused by nutrient leaching. Appropriate irrigation and fertilisation management are essential for improving crop productivity and developing sustainable agriculture in the HID.

A two-year field experiment investigated the effects of irrigation and fertilization regimes on soil water, nitrogen accumulation and distribution in the soil profile and plant organs, nitrogen use efficiency, and economic benefits of spring maize (*Zea mays* L.) under film mulched ridge–furrow system. Three irrigation levels – I1 (high, 400 mm), I2 (medium, 300mm), and I3 (low, 200mm) – and two fertilisation levels – F1 (high, 300kg N ha–1) and F2 (low, 150kg N ha–1) were designed. Mean soil NO3−-N contents did not significantly differ between I2 and I3 and were significantly higher than I1. I1F1 and I1F2 remarkably increased soil NO3−-N accumulation in the 80 – 100cm soil layer at harvest. High irrigation increased the risk of N leaching into the deep soil layer. I2F2 increased plant nitrogen accumulation and promoted nitrogen transport to grains, improved nitrogen harvest index, and internal use efficiency.

This research concludes that the film mulched ridge-furrow irrigation system with 300mm irrigation and 150kg N ha–1 fertilisation is a promising approach for reducing water supply and nitrogen leaching and obtaining acceptable grain yield and economic benefits for spring maize production in the upper Yellow River Basin of China.

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



Leaf area index, dry matter accumulation, and harvest index of spring maize under different irrigation and nitrogen fertiliser treatments in 2017 and 2018.

Effect of natural factors and management practices on agricultural water use efficiency under drought: A meta-analysis of global drylands

Project team: Dr Liuyang Yu[2], Professor Xining Zhao[2,3] (project leader; h.x.zhao@163.com), Professor Xiaodong Gao[2,3], Ruhao Jia[2], Menghao Yang[2,3], Associate Professor Xiaolin Yang[4], Dr Yong Wu[5], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Northwest A&F University, China; [3]Chinese Academy of Science & Ministry of Water Resources; [4]China Agricultural University, China; [5]National Agro-Tech Extension and Service Center, China

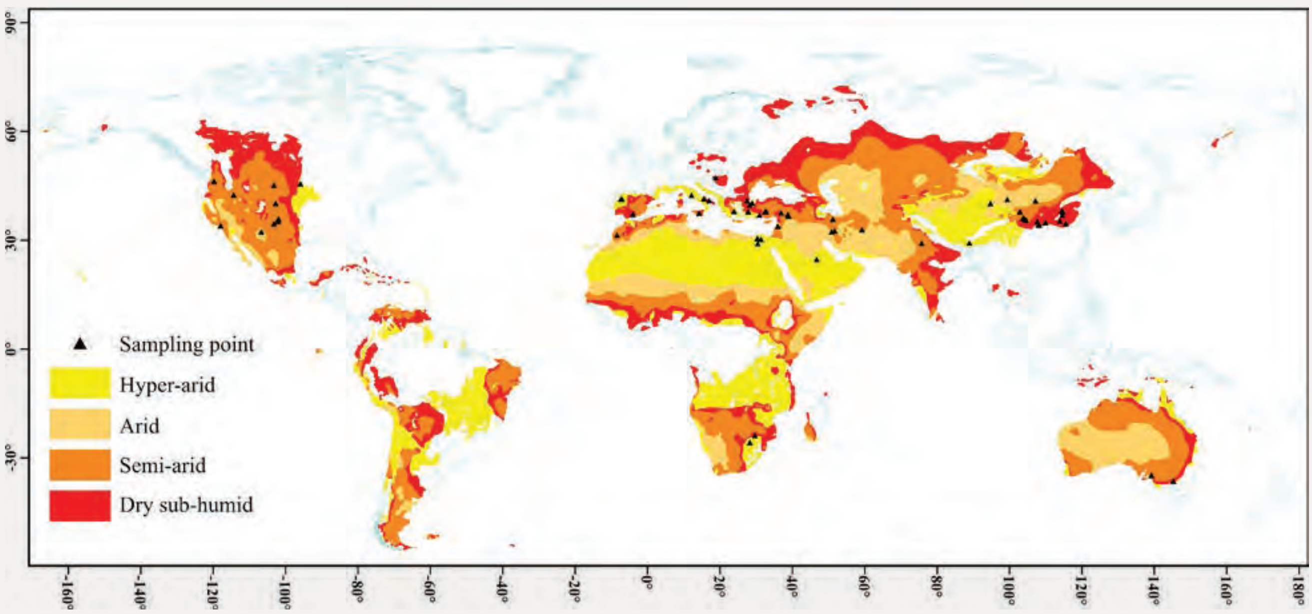
Agriculture's need to feed the growing population is challenged by the decline in available water resources especially in the context of global climate change. Improving crop water use efficiency (WUE) will help to safeguard the environmental sustainability of food production in dryland areas. However, the impact of drought on crop WUE varies – a comprehensive and quantitative understanding of relevant factors is needed to support evidence-based management decisions.

Here, we used a meta-analysis of global drylands (81 studies with 836 paired observations) to evaluate the response of various crop WUEs to drought based on various natural and human induced factors. Our results showed that responses of crop types' WUE varied under drought intensity, which probably a reference for crop selection in drylands. Cotton could be one of crop selection reference in hyper-arid or arid regions, and legume is not recommended for drylands without irrigation.

Cereal crops are suitable for growing in semi-arid or dry sub-humid areas. Moreover, soil improvement and fertilizer management are the effective methods to alleviate drought stress, in addition to irrigation. Soil with medium-texture, 1.3–1.4g cm–3 bulk density and 15–20g kg–1 organic matter is beneficial for improving WUE under drought. Fertiliser should be carefully considered and not exceed 200 kg ha–1 for wheat in drylands. Water deficit can improve crop WUE, but should not exceed 40 per cent of the full irrigation amount. Field management practices, such as mulching and weed control, can help alleviate drought by regulating WUE to some extent.

This study evaluated the responses of various crop WUEs to drought and highlighted the factors contributing to and/or decreasing crop WUE from natural factor and management practices, which provides a basis for agricultural drought mitigation strategies under future climate change in dryland areas.

This research is supported by the National Key Research and Development Program, National Natural Science Foundation of China, Shaanxi Innovative Research Team for Key Science and Technology, 111 Project, and CAS Youth Scholar of West China Program.



World map showing the 81 study sites included in the dryland meta-analysis. Climate zones included in this dataset are: hyper-arid, arid, semi-arid, and dry sub-humid, in accordance with the United Nations Convention to Combat Desertification (UNCCD) definition of drylands.

Water/ climate nexus environmental rural-urban migration and coping strategies

Project team: Dr Ameneh Mianabadi[2,3] (project leader; amianabadi@stu.um.ac.ir) Dr Kamran Davary[2], Dr Mahdi Kolahi[2], Dr Judith Fisher[1]

Collaborating organisations: [1]UWA; [2]Ferdowsi University of Mashhad, Iran; [3]Graduate University of Advanced Technology, Iran

Rural-urban migration is a challenging issue for communities and is influenced by interactions between numerous push and pull factors. To better understand the interacting drivers of rural-urban migration, the study investigates the factors which influence migration from rural areas in Sistan to Mashhad city in Iran.

The investigation was conducted using questionnaires and deep interviews. The results show that the main reason for migration from Sistan to Mashhad is environmental degradation including drought and water scarcity, followed by economic and government operational plans for supporting rural people. However, some people stay in Sistan in spite of the current unpleasant environmental and economic conditions. The results demonstrated cultural and social factors as the main motivations for people remaining in villages. Since the factors could be more challenging under future global warming, adaptive participatory governance is needed to link civil society, authorities, scientists, and the land to develop nature-based and rural-urban migration solutions.

The Hirmand River in the Sistan Province of Iran is one of two major water resources for the area

Assessing the performance of advanced machine learning algorithms to predict soil moisture profiles across an agricultural region

Project team: Atbin Mahabbati[1], Professor Jason Beringer[1] (project leader; jason.beringer@uwa.edu.au), Associate Professor Matthias Leopold[1], Dr Caitlin Moore[1], Thomas G. Van Niel[2], Saeedreza Shehnepoor[2], Dr Mohammad Ahangar Kiasari[2]

Collaborating organisations: [1]UWA; [2]CSIRO; The OzFlux Network; DPIRD

By regulating the water balance between the soil and the atmosphere, soil moisture has a noticeable impact on crop growth. Also, soil moisture is well-known as a key indicator of water stress for vegetation and is used to track agricultural drought. In order to effectively employ fertilisers, primarily when the fertiliser is intended to be applied below the surface, soil moisture is the most crucial factor to be considered. However, due to the existing models' coarse-resolution products, they are not suitable for field-scale applications (e.g. 5km provided by the Australian Water Availability Project).

The lack of almost real-time soil moisture data can be addressed by creating deep learning models, which can be done given the recent rapid advancements in artificial intelligence and the availability of high-resolution satellite images. Our goal is to build and optimise a soil moisture estimation model to achieve a high precision assessing soil moisture profile across the WA Wheat belt. Deep learning models outperform traditional methods for solving complex problems, time series analysis, and image processing.

We have been working closely with the UWA Department of Computer Science and Software Engineering professionals to construct such a complex model. A step-by-step road map is provided that contains all necessary data (e.g. the required form of input data, the data sources, the most suitable deep learning methods, and so forth).

Providing a daily 3D map of soil moisture profile across the Wheatbelt, the model would help farmers whenever they need reliable soil moisture estimates. For instance, farmers could find the best time for planting, whether the soil moisture is enough, and the most suitable time for applying fertilisers. These timings have a huge impact on optimising costs and knowing the timings can have a big effect on maximising the production and benefits of farms.

Unfortunately, the proposed model did not provide a promising performance in the first testing attempt, mainly due to low data resolution and not using the ground-based ancillary data. The team is working on a second version of the primary model to address the issues and improve the results. The outcome of the second version of the model will be published by the end of 2022.

This research is supported by the Australian Government International RTP, UPA living allowance, and UWA Safety Net Top-up Scholarship.

PhD candidate Atbin Mahabbati pictured at UWA.

Response of mungbean (cvs. Celera II-AU and Jade-AU) and blackgram (cv. Onyx-AU) to transient waterlogging

Project team: Khin Lay Kyu[1], Dr Al Imran Malik[1], Professor Timothy Colmer[1], Hackett Professor Kadambot Siddique[1], Professor William Erskine[1] (project leader; william.erskine@uwa.edu.au)

Collaborating organisations: [1]UWA; ACIAR

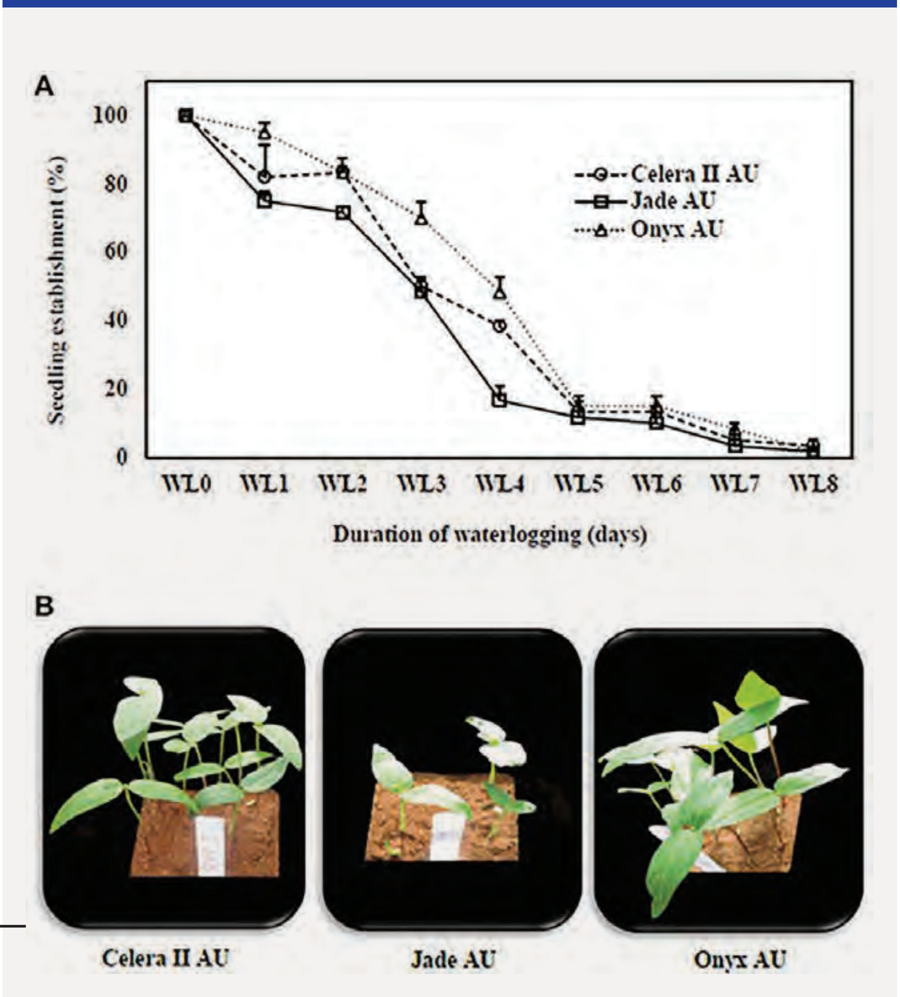
Mungbean (*Vigna radiata* L. Wilczek) and blackgram (*Vigna mungo* L. Hepper) are important crops for smallholder farmers in tropical and subtropical regions. Production of both crops is affected by unexpected and increasingly frequent extreme precipitation events, which result in transient soil waterlogging.

This study aimed to compare the waterlogging tolerance of mungbean and blackgram genotypes under the varying duration of waterlogging stress at germination and seedling stages. We evaluated the responses to different durations of transient waterlogging in a sandy clay loam under temperature-controlled glasshouse conditions. Waterlogging durations were 0, 1, 2, 3, 4, 5, 6, 7, and 8 days during germination and 0, 2, 4, 8, and 16 days during the seedling stage. We used two mungbean genotypes (green testa), Celera II-AU (small-seeded), and Jade-AU (large-seeded), contrasting in seed size and hypocotyl pigmentation, and a blackgram genotype (black testa), Onyx-AU.

Waterlogging reduced soil redox potential, delayed or even prevented germination, decreased seedling establishment, and affected shoot and root development. In the seedlings waterlogged (WL) at 15 days after sowing (DAS), adventitious root formation and crown nodulation varied between the genotypes, and 16 days of waterlogging substantially reduced growth but did not result in plant death. Plants in soil with waterlogging for 8–16 days followed by drainage and sampling at 39 DAS had reduced shoot and root dry mass by 60–65 per cent in mungbean and 40 per cent in blackgram compared with continuously drained controls, due at least in part to fewer lateral roots.

Soil plant analysis development (SPAD) chlorophyll content was also reduced. Onyx-AU, a blackgram genotype, was more tolerant to transient waterlogging than Jade-AU and Celera II-AU in both growth stages. Of the two mungbean genotypes, Celera II-AU had a greater seedling establishment than Jade-AU post waterlogging imposed at sowing. In contrast, Jade-AU had more plant biomass and greater recovery growth than Celera II-AU after waterlogging and recovery during the seedling stage. Both species were delayed in emergence in response to the shorter periods of transient waterlogging at germination, and with the longer waterlogging germination and emergence failed, whereas at the seedling stage both showed adaptation by the formation of adventitious roots.

This research is supported by the John Allwright Fellowship Award from ACIAR.



Seedling establishment (per cent) of (A) mungbean (°) Celera II-AU, (ʾ) Jade-AU and blackgram (Δ) Onyx-AU after different durations of waterlogging.

A plentiful fruit stall at the iconic Fremantle Markets, WA.
Photo: Natasha Atkinson

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.

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Associate Professor Michael Considine preparing to sample bud material in Margaret River. Photo: Dr John Considine

The bud dormancy disconnect: latent buds of grapevine are dormant during summer despite a high metabolic rate

Project team: Dr Yazhini Velappan[1], Dr Tinashe Chabikwa, Dr John Considine[1], Dr Patricia Agudelo-Romero[1], Professor Christine Foyer[2], Dr Santiago Signorelli[1,3], Associate Professor Michael Considine[1,4] (project leader; michael.considine@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]University of Birmingham, UK; [3]Universidad de la República, Uruguay; [4]DPIRD

Answering the question of why latent grapevine buds are unable to resume growth in summer could lead to better managing the effects of climate change in crops. UWA researchers investigated the apparent disconnect between dormancy and the underlying metabolism of grapevine buds, from bud set in summer to bud burst in spring.

Grapevine (*Vitis vinifera* L.) is the most economically important fruit crop worldwide, grown commercially on all continents except Antarctica. Dormancy is a seasonal condition of inactivity that is common among woody perennial plant species, including many commercial fruit-producing species. The transition to dormancy suspends vegetative and reproductive growth and protects embryonic organs during unfavourable conditions such as winter frost. Dormancy is made up of numerous processes (such as growth, metabolism and vascular) that are influenced by climate factors. The expression of dormancy for any one species or variety varies in different seasons and climates and can have a large influence on fruit or seed production in the following year.

Over two consecutive years, the researchers evaluated the competence of bud growth from 275 Merlot grapevines in the Margaret River region of WA. In addition to RNA sequence data analysis, they measured the depth of dormancy, effect of climate and chilling, bud moisture content, bud respiration and internal bud oxygen partial pressure. The data revealed a pronounced peak of dormancy in late summer followed by a two-phase release from dormancy during autumn and late winter.

The findings established a clear disconnect between the capacity to grow and metabolic and transcriptional regulation. Researchers observed an extreme resistance of explants (plant samples) collected in late summer to resume growth, which was not consistent with the seasonal dynamics of climate, physiology or gene expression. This study provides critical insight to the understanding of the regulation of dormancy.

A greater understanding of dormancy transitions is integral to better managing the effects of climate change in forest and crop systems. Grapevines display considerable plasticity to climate and seasonality. Understanding the relationship between metabolism, cell signalling, and growth physiology will enable changes in practice that accommodate regional climate change and increased productivity in marginal, warmer climates.

This research is supported by the ARC, Australian Government, UWA, and Wine Australia.

Single node explant in growth-forcing conditions, as used to test dormancy. Photo: Dr Santiago Signorelli

Unpacking grapevine leafroll disease at the molecular level

Project team: Associate Professor Michael Considine[1,2] (project leader: michael.considine@uwa.edu.au), Wisam Salo[1], Colin Gordon[1], Dr John Considine[1], Professor Chris Winefield[3]

Collaborating organisations: [1]UWA; [2]DPIRD; Wines of Western Australia; Peter Nuich; [3]Lincoln University, USA

PhD candidate Wisam (Sam) Salo's thesis took a deep dive into understanding the effects of virus effects on table grape quality. Mr Salo came to study at UWA as an already accomplished molecular biologist from Iraq – making the switch from human disease to plants. His work built on earlier findings that grapevine leafroll-associated Viruses (GLRaV) can influence berry size and colour in table grapes.

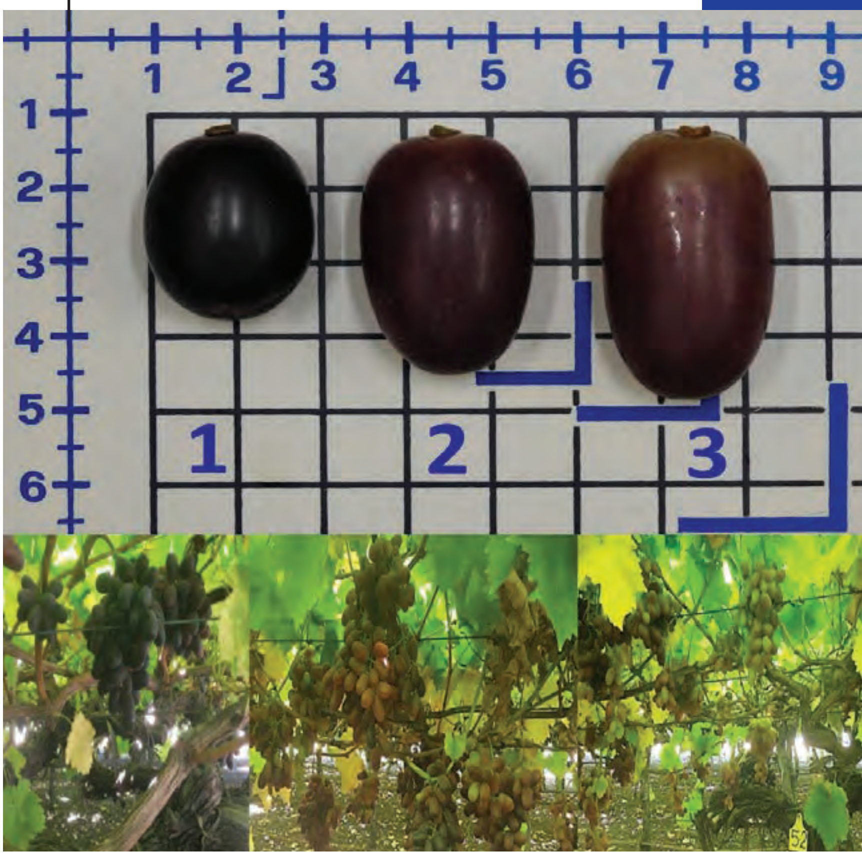
Grapevine leafroll disease, caused by GLRaVs, can devastate vine production in table and wine grapes. It can result in decreased yield, delayed ripening and decreased berry quality. Viral diseases are particularly devastating in horticulture and perennial tree crops, as the virus cannot be eradicated non-destructively. GLRaV comprise a family of RNA viruses, which appear to have differing consequences for vine productivity. Before Mr Salo started his PhD, the molecular mechanism of the effects of virus on fruit quality was not known.

Mr Salo's research drew on an experimental set of vines (cv. Crimson Seedless) first established by DPIRD in the early 2000's. This included uninfected vines, vines infected with one strain of virus only (GLRaV-3) and vines infected with a mixture of viruses (GLRaV-3, GLRaV-9, GVA). Each of these viruses is known to be present in WA vineyards. Berries of infected vines clearly showed delayed ripening, increased berry size and were less able to achieve desirable colour than the uninfected control vines. Mr Salo established that viral load, i.e., the copy number of each virus, had no relationship on berry quality. This has implications for the development of diagnostic tests to predict incidence of grapevine leafroll disease. Mr Salo took this to the next level and one beyond it, by firstly investigating the changes in mRNA and then small RNA (miRNA). mRNA is the messenger information that translates into protein and function. miRNA are involved in gene silencing, directing the destruction of mRNA before proteins are synthesised. Mr Salo found broad agreement in the signatures of these molecular profiles, which implicates the activation of specific groups of miRNA by viral infection, which then target mRNA genes responsible for hormone synthesis. In this way, the virus causes a dysregulation of hormone function during ripening, which explains the delayed ripening, lack of colour and enlarged berries.

This research is supported by the ARC Linkage Project and ARC Future Fellowship.

Sam Salo following thesis submission, with supervisor Associate Professor Michael Considine.

Var. Crimson Seedless table grapes; uninfected control (left) and two independent infected vines (middle and right) showing the influence of grapevine leafroll-associated virus on berry quality and size.



Australian honeypot ant (*Camponotus inflatus*) honey—A comprehensive analysis of the physiochemical characteristics, bioactivity, and HPTLC profile of a traditional Indigenous Australian food

Project team: Md Khairul Islam[1,2], Ivan Lozada Lawag[1,2], Tomislav Sostaric[1], Edie Ulrich, Danny Ulrich, Terrence Dewar[3], Professor Lee Yong Lim[1], Dr Cornelia Locher[1,2] (project leader; connie.locher@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]CRC for Honey Bee Products Ltd; [3]Australian Biome

Honey derived from bees has been extensively analysed around the world, yet very few studies have been conducted on the unusual insect honey produced by WA honeypot ants. Sometimes referred to as 'living pantries', honeypot ants (*Camponotus inflatus*) have abdomens swollen with honey to the size of a small marble, which can be regurgitated to feed the colony in times of scarcity.

This study is the first comprehensive analysis of honeypot ant honey, which was collected 50km east of Kalgoorlie in the Goldfields region of WA. It collated baseline data on the honey's physicochemical properties and its antioxidant activity and determined its phenolics profile and its major sugars by High Performance Thin Layer Chromatography to compare with honey produced by honeybees.

While in many respects ant honey was found to be similar, it also showed some interesting differences. The ant honey had a higher water content compared to typical honeybee-derived honey. Additionally, a noticeable difference was also found in the ant honey's main sugars – glucose was present in higher quantities than fructose, which is opposite to many honeybee-derived types of honey.

The study also found evidence of a currently unidentified sugar in the ant honey. According to the taste panellists, the ant honey was less sweet and slightly sour compared with a honeybee honey sample – despite having a total sugar content of 67g per 100g. As an acidic environment is seen as less conducive for microbial growth, the acidity of honey is considered as one factor that contributes to honey's antibacterial activity. Future research should therefore explore the antibacterial activity of ant honey.

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

Edie Ulrich and her sister Margorie Stubbs collecting honeypot ants in the Goldfields.

The honeypot ants collected for the study.

Using High Performance Thin Layer Chromatography to identify the unique chemical signature of different Western Australian honey varieties

PhD candidate Md Khairul Islam displaying the honey signatures from the HPTLC analysis.

Project team: Md Khairul Islam[1,2], Dr Cornelia Locher[1,2] (project leader; connie.locher@uwa.edu.au); Kevin Vinsen[3]

Collaborating organisations: [1]UWA; [2]CRC for Honey Bee Products Ltd; [3]ICRAR

UWA PhD candidate Md Khairul Islam is working with the International Centre for Radio Astronomy Research (ICRAR) to identify the unique chemical signature of different Western Australian honey varieties.

The flavour profile of a honey is dependent on the different plants that the bee feeds on. Plant nectars all contain different phenolics, such as flavonoids, and also a whole range of other compounds. The bee will take that nectar into the honey, and the chemical signature stays there. Given that bees typically feed on many different flowers – and with more than 250 plants for WA bees to choose from – beekeepers have previously been unable to confirm the exact flavour signature of their honey.

In the study so far, the research team has been able to identify the key nectar signature of some iconic WA honeys using High Performance Thin Layer Chromatography (HPTLC) such as jarrah, marri, red bell and coastal peppermint. Internationally, this method has already been adopted by analytical industries and applied to routine quality control or analysis of honeys.

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

Dr Liz Barbour, Kevin Vinsen, Professor Cornelia Locher and Md Khairul Islam.

Development of a Vitamin K database for commercially available food in Australia

Project team: Dr Marc Sim[1,2] (project leader; marc.sim@uwa.edu.au), Dr Claire Palmer[1,2], Henrietta Koch[1], Dr Sujata Shinde[1], Dr Lauren Blekkenhorst[1,2], Associate Professor Joshua Lewis[1,2,3], Professor Kevin Croft[1], Professor Jonathan Hodgson[1,2]

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

In this study, researchers found that a diet rich in vitamin K can dramatically reduce the risk of cardiovascular disease related to atherosclerosis (plaque build-up in the arteries). The research examined data from a Danish health study of fifty thousand people over 23 years.

Vitamin K1 is found in green leafy vegetables and vegetable oils, while vitamin K2 is found in meat, eggs, and fermented foods. The study found that people with the highest intakes of vitamin K1 were 21 per cent less likely to be hospitalised with the cardiovascular disease related to atherosclerosis. For vitamin K2, the risk of being hospitalised was 14 per cent lower.

This lower risk was seen for all types of heart disease related to atherosclerosis, particularly for peripheral artery disease at 34 per cent. These findings shed light on the potentially important effect that vitamin K has on the killer disease and reinforces the importance of a healthy diet in preventing it.

This research is supported by a Royal Perth Hospital Research Foundation Springboard Grant

A variety of foods rich in vitamin K.

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

Project team: Professor Wallace Cowling[1] (project leader; wallace.cowling@uwa.edu.au), Dr Renu Saradadevi[1], Hackett Professor Kadambot Siddique[1], Dr Clare Mukankusi[2], Winnifred Amongi[2], Jean-Claude Rubyogo[3], Dr Teshale Assefa[4], Annuarite Uwera[5], Dr Berhanu Fenta[6], Eric Nduwarugira[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 in Africa is led by The Alliance of Bioversity International and CIAT (CIAT-Uganda) which includes the Pan Africa Bean Research Alliance (PABRA). 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*). Our 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 during the 5 years of this project. Rapid cooking bean varieties will decrease the time and cost of cooking, while encouraging better health and vitality in African women and children who will benefit from higher Fe and Zn in new biofortified bean varieties.

In 2021, we published a journal article describing the genomic breeding values for grain yield, CKT, Fe and Zn content in 350 bean varieties in the African bean panel and designed a crossing program based on OCS to accelerated genetic gain in these traits. Genetic gain was measured in four major market groups of beans which match PABRA's bean market targets in East Africa.

All breeders and technicians at partner institutions in East Africa were trained in trial design and analysis and in operation of a database system (BMS) which links trials and data across the partners. In 2021, partners conducted field trials of the first cross progeny and uploaded the field and laboratory data into BMS. Pedigree and genomic information were used to analyse genomic breeding values for grain yield, CKT, Fe and Zn in the first cycle progeny in the breeding program.

Partner countries selected within the first cycle progeny to continue testing in their region and to select potential new varieties within their preferred market classes. The subsequent 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.

The unique breeding method being implemented in east Africa in this ACIAR project is based on methods developed by Professor Cowling at UWA and is abbreviated in the acronym BRÍO (https://research.aciar.gov.au/rapidcookingbeans/brio).

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

Screenhouse technician Stephen Musoke monitoring common bean plants at the Alliance of Bioversity International and CIAT, Kampala Uganda.

Association between fruit and vegetable intakes and mental health in the Australian diabetes obesity and lifestyle cohort

Project team: Dr Joanna Rees[2] (project leader; j.rees@ecu.edu.au), Dr Simone Radavelli Bagatini[2], Dr Johnny Lo[2], Professor Jonathan Hodgson[1,2], Associate Professor Claus Christophersen[2,3], Professor Robin Daly[4], Professor Dianna Magliano[5], Professor Jonathan Shaw[5], Dr Marc Sim[1,2], Dr Catherine Bondonno[1,2], Dr Lauren Blekkenhorst[1,2], Professor Joanne Dickson[2], Dr Joshua Lewis[1,2,6], Professor Amanda Devine[2]

Collaborating organisations: [1]UWA; [2]ECU; [3]Curtin University; [4]Deakin University; [5]Baker Heart and Diabetes Institute; [6]The University of Sydney

Increasing prevalence of mental health disorders within the Australian population is a serious public health issue. Adequate intake of fruits and vegetables, dietary fibre and resistant starch is associated with better mental and physical health. Few longitudinal studies exist exploring the temporal relationship.

Using a validated food frequency questionnaire, the research team examined baseline fruit and vegetable intakes of 5845 Australian adults from the AusDiab study and estimated food group-derived dietary fibre and resistant starch using data from the literature. Perceived mental health was assessed at baseline and five-year follow up using SF-36 mental component summary scores.

The researchers conducted baseline cross-sectional analysis and prospective analysis of baseline dietary intake with perceived mental health at five years. Higher baseline fruits and vegetables, and fruits and vegetable-derived dietary fibre and resistant starch intakes, were associated with better five-year mental component summary. A higher fruits and vegetables intake at baseline had 41 per cent lower odds of mental component summary below population average (<47) at five-year follow up. An inverse association was observed with discretionary food-derived dietary fibre and resistant starch. This demonstrates the association between higher intakes of fruits and vegetables, and fruits and vegetable-derived dietary fibre and resistant starch, with better five-year mental health outcomes.

Nutrition is a critical component for consideration when addressing mental health and wellbeing.

Calm *Hu* ram lambs assigned by temperament classification are healthier and have better meat quality than nervous *Hu* ram lambs

Project team: Dr Jinying Zhang[2], Shuhan Qian[2], Jiahao Chen[2], Luoyang Ding[1,2] (project leader; luoyang.ding@research.uwa.edu.au), Associate Professor Mengzhi Wang[2], Professor Shane Maloney[1], Associate Professor Dominique Blache[1]

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

The objective of this study was to evaluate the effects of temperament classification (assessed using an arena test) on health and productivity of *Hu* ram lambs. In experiment one, eight ram lambs classified as calm and eight classified as nervous (selected from 100 ram lambs) were fed individually for 60 days to compare food intake, food digestibility, weight gain, and biochemical indices of health. In experiment two, nine ram lambs classified as calm and nine classified as nervous (selected from 150 ram lambs) were fed in a group and slaughter traits, meat quality, and muscle histology were compared. Calm lambs had higher dry matter digestibility, lower serum TNF-alpha, higher total antioxidant capacity, total superoxide dismutase activity, dressing percentage, cross-sectional area of loin and myofibre density. They also had lower ultimate pH of the meat, and higher meat redness, than nervous lambs. Selection for calm temperament could be beneficial to health, slaughter, and carcass traits in *Hu* ram lambs.

The results of this study indicate that the nervous *Hu* ram lambs have more pronounced behavioural responses to the same stressor than do calm Hu ram lambs. Subsequently, the nervous Hu ram lambs likely experienced higher stress during the feeding period, and the pre-slaughter period at the abattoir, leading to lower dry matter digestibility, dressing percentage, serum total superoxide dismutase and total antioxidant capacity activities, but higher serum TNF-alpha concentration, and poorer meat quality than the calm *Hu* ram lambs. Thus, the selection for calm temperament through behaviour tests will be beneficial to the health, meat production, and animal welfare in *Hu* ram lambs that are managed indoors.

This research is supported by the Innovation Project of Students from Yangzhou University.

Hu sheep originated from Mongolian sheep and are raised indoors all year round.

A drone image of one of PhD candidate Monica Danilevic's field experiments. Photo: Roberto Lujan Rocha

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, in order to undertake research and development focused on bringing about commercial innovation.

Theme Leaders

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The Boyagin Wandoo Woodland SuperSite.

Ecosystem monitoring in WA's wheatbelt

Project team: Professor Jason Beringer[1] (project leader; jason.beringer@uwa.edu.au), Dr Caitlin Moore[1]

Collaborating organisations: [1]UWA

The Terrestrial Ecosystem Research Network's (TERN) Boyagin Wandoo Woodland SuperSite is located in remnant Eucalyptus wandoo woodland within the Boyagin Rock Nature Reserve, about 175km southeast of Perth, WA. Monitoring of the Wandoo woodland ecosystem is paired with a nearby managed ecosystem located at UWA Farm Ridgefield, which is used for wheat and canola cropping and sheep grazing.

The National Collaborative Research Infrastructure Strategy (NCRIS)-enabled TERN Boyagin SuperSite is operated by UWA's Professor Jason Beringer, Dr Caitlin Moore and Tim Lardner with support from the WA Government. The Boyagin Wandoo Woodland SuperSite and Ridgefield OzFlux site are located approximately 4 km apart and provide an ideal pair of flux monitoring towers to help understand landscape dynamics in the WA wheatbelt. The cropping and grazing systems of WA's wheatbelt alone have been valued at around AU$2.7 billion, a figure that does not consider the ecosystem services value of the remnant pockets of biologically significant natural ecosystems, such as that at the Boyagin Wandoo Woodland SuperSite.

Monitoring equipment at the two sites quantify the exchanges (fluxes) of carbon, water and energy between the land and atmosphere and between the two different land use types. The data are used by researchers from across Australia to contrast how past, current and future climate variability is likely to impact these two ecosystems.

2021 research highlights for the sites included addition of new hyperspectral sensing equipment that will enable the real-time monitoring of spectral vegetation indices (i.e. the NDVI – normalised difference vegetation index) as well as sun-induced chlorophyll fluorescence, which is closely coupled to vegetation productivity.

This research is supported by TERN-NCRIS and the WA State Government through the Department of Jobs, Tourism, Science and Innovation.

The UWA Farm Ridgefield OzFlux site.

These sensors have now been assembled on drone platforms for on-farm applications.

Weed Chipper research wins Most Outstanding Paper Award

Project team: Dr Andrew Guzzomi[1] (project leader; andrew.guzzomi@uwa.edu.au), Dr Carlo Peressini[1], Associate Professor Michael Walsh[2]

Collaborating organisations: [1]UWA; [2]University of Sydney; Precision Agronomics Australia

A paper capturing the research behind the unique mechanical Weed Chipper received the Most Outstanding Paper Award for publications in early 2021. Project leader, USYD Associate Professor Michael Walsh, accepted the award on behalf of the project team at the Weed Science Society of America's virtual 2021 Annual Conference in February. The paper, published in the *Weed Technology* journal, highlights the innovativeness of the unique mechanical system that provides an alternative to using herbicides for weed management in large-scale cropping operations.

The Weed Chipper uses specifically-designed rapid response 'tynes' that behave like mechanical hoes, coupled with commercially-available sensing technology to detect and chip out weeds in fallow fields. It is the first mechanical system capable of site-specific weed control in Australian grain production. UWA's inaugural agricultural engineer Dr Andrew Guzzomi, who led the engineering design of the weed chipper, said the award came after performing extensive research, development and testing with a multidisciplinary team and industry partners.

The Most Outstanding Paper Award demonstrated the merit of the innovation and the potential impact that mechanical non-chemical approaches could have in helping combat the persistence of tough-to-kill herbicide resistant weeds. It was the most recent accolade for the Weed Chipper, which also won the Rio Tinto WA Innovator of the Year emerging category award in 2019.

This research is supported by GRDC.

The UWA co-developed Weed Chipper in the field.

Portable multispectral/hyperspectral sensors for crop management

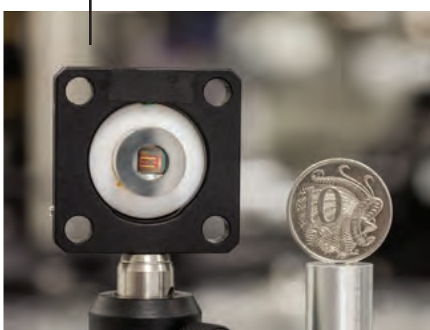
Project team: Dr Dilusha Silva[1] (project leader; dilusha.silva@uwa.edu.au), Associate Professor Gino Putrino[1], Michal Zawierta[1], Dr Dhirendra Tripathi[1], Dr Hemendra Kala[1], Associate Professor Mariusz Martyniuk[1], Professor Lorenzo Faraone[1]

Collaborating organisation: [1]UWA

This ongoing research project aims to develop small, portable, robust infrared spectrometer modules that are suitable for a host of applications, including crop management. In the past these devices have been demonstrated only in the lab environment, but work is now proceeding to demonstrate the technology as a working prototype suitable for hand-held, or drone-mounted application. A drone mountable sensor will be demonstrated and test-flown in January 2022.

This research is supported by multiple organisations including GRDC, USA and Australian defence organisations, and the ARC.

Portable multispectral/hyperspectral sensors are being developed for crop management.



New weed detection model for Australian farmers

Project team: Monica Danilevicz[1], Roberto Lujan Rocha[2], Michael Ashworth[2], Professor David Edwards[1] (project leader; dave.edwards@uwa.edu.au)

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

With climate change impacting crop production and threatening food security worldwide, this project is expected to help growers to protect crop yield and support Australia's role as a major food provider worldwide, as it is estimated that weeds cost AUD $3.3 billion annually to Australian grain growers.

Weed scientists can also employ the weed detection model to quantify the effectiveness of herbicide treatments in these species at the Australian Herbicide Research Initiative.

This research is supported by UWA and the Forrest Research Foundation.

PhD candidate Monica Danilevicz in the field.

UWA Centre for Engineering Innovation: Agriculture & Ecological Restoration

Project team: Dr Andrew Guzzomi[1] (project leader; andrew.guzzomi@uwa.edu.au), Adjunct Professor Michael Walsh[1], Dr Todd Erickson[1,2], Hannah Demerise[1], Dr Carlo Peressini[1], Dr Monte Masarei[1], Wesley Moss[1], James Boyle[1], Toan Nguyen[1], William Richards[1]

Collaborating organisations: [1]UWA; [2]Botanic Gardens and Parks Authority

In 2021, Dr Andrew Guzzomi founded the Centre for Engineering Innovation: Agriculture & Ecological Restoration (CEI:AgER) at UWA. The Centre's establishment comes on the back of building strong relationships with innovative farmers and industry groups and sustained track record of solving interdisciplinary challenges facing the agricultural and environmental sectors. CEI:AgER leverages existing and builds new interdisciplinary partnerships between UWA, industry, government, farmers and scientists across Australia and increasingly internationally.

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 2021 include participating in the Shenton Park Field Station Staff Open Day in September, being awarded AUD $2 million from the Department of Agriculture, Water and Environment to develop targeted tillage for row cropping systems, and filing Australian Provisional Patents for two direct seeding devices.

This research is supported by UWA.

Dr Andrew Guzzomi and research colleagues at the CEI AER during the 2021 Shenton Park Field Station Staff Open Day.

Profitable and environmentally sustainable subclover and medic seed harvesting

Project team: Associate Professor Phillip Nichols [1] (project leader; phillip.nichols@uwa.edu.au), Dr Andrew Guzzomi[1], Dr Kevin Foster[1], Professor Megan Ryan[1], Professor William Erskine[1], Wesley Moss[1]

Collaborating organisation: [1]UWA

This project has been operating since October 2018 and aims to develop innovative solutions to increase subterranean clover and annual medic seed harvesting efficiency and reduce soil erosion impacts of the commonly used Horwood Bagshaw vacuum seed harvesters. The project has mainly focussed on subterranean clover, due to the difficulty of extracting its seed-bearing burrs from the soil.

Preliminary field experiments have shown that a modified, commercial peanut digger has considerable potential for bringing burrs to the soil surface and inverting them to dry out fully. This then allows burrs to be picked up for threshing. However, this change in harvesting method is likely to require changes to seed crop agronomy, as the digging process appears best conducted prior to complete plant senescence, which is when vacuum harvesting is conducted.

Seed development studies have been conducted in parallel to better understand the potential implications on seed yield and quality parameters from harvesting prior to complete senescence.

A major highlight was the submission of postgraduate student Wesley Moss' PhD thesis, following publication of four peer-reviewed journal and two conference papers.

This research is supported by AgriFutures Australia, the Robert and Maude Gledden Postgraduate Scholarship, and AW Howard Memorial Trust Research Fellowship.

Wesley Moss outlining his PhD project at The UWA Institute of Agriculture Postgraduate Showcase in June 2021.

Harvesting subterranean clover seed with a peanut digger at the UWA Shenton Park Field Station. From left to right: Dr Andrew Guzzomi, Associate Professor Phil Nichols and Dr Kevin Foster.

Drones as a rapid scouting method to detect aphid-induced stress in wheat crops

Project team: Caroline Chua[1], Associate Professor Ken Flower[1], Associate Professor Nik Callow[1], Dr Dustin Severtson[2] (project leader; dustin.severtson@dpird.wa.gov.au), Amber Balfour-Cunningham[2]

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

The current methods to scout grain crops for pests and diseases are time-consuming and often inaccurate. Random sampling hopes to find pest hotspots in parts of paddocks, but often miss them. This means growers are either losing money on unnecessary pesticide application or yield loss in parts of crops which are missed.

Spatial data, such as remote sensing using near-infrared and infrared spectra, can effectively detect and map regions of crops that are experiencing biotic or abiotic stress. This research project investigated whether drones could be a useful method for rapid scouting of wheat crops to detect aphid-induced stress.

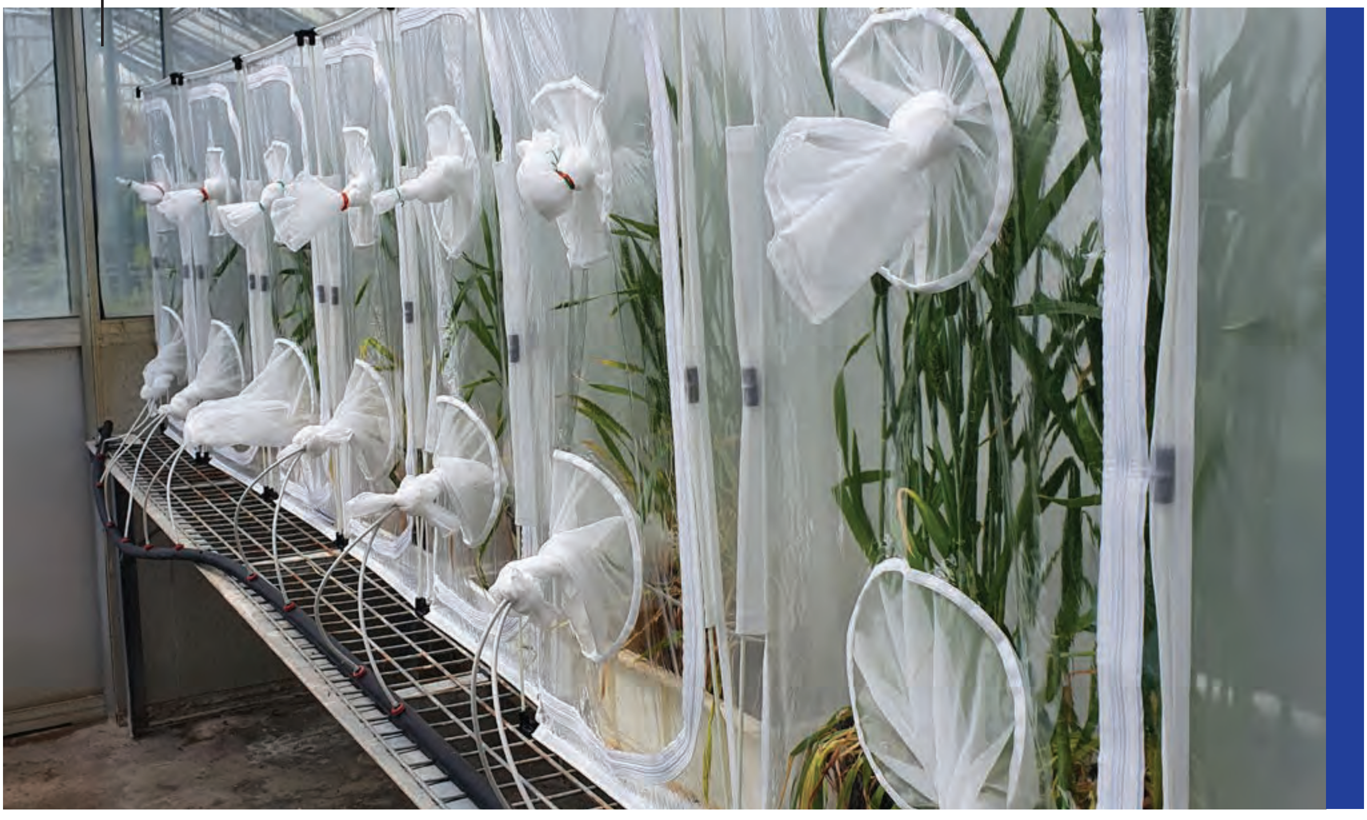
Prior research has shown the potential for using reflectance indices to identify stressed areas of canola crops impacted by biotic (e.g. aphid) and abiotic (e.g. potassium deficiency) factors. The specific objective of the project was to determine which reflected wavelengths were changed after infesting wheat plants with aphids, and if these could be detected using drone-based multispectral sensors.

A field trial was seeded at DPIRD in Northam and plots were infested with different levels of aphid. A multispectral drone was used to image the plots along with ground-based aphid counts and leaf chlorophyll (SPAD) measurements. Unfortunately, heavy rains in the main growing season prevented large numbers of aphids accumulating in the plots, so there were few differences detected between aphid-infested and control plots. As a result, a separate pot experiment was established at the UWA Plant Growth Facility, where wheat plants were grown and then infested with different levels of aphid. The pots were kept in 'bug-dorms' to prevent the aphids spreading within the glasshouse. The control and infested plants/leaves were imaged on several occasions with a multispectral camera and spectroradiometer to assess reflectance data under more controlled conditions.

The spectroradiometer was able to detect aphid-induced stress two days into the infestation, through increased yellow, red and short-wave infrared reflectance. This was eight days earlier than visual symptoms. Therefore, there is potential for this method to detect aphid-induced stress, but field validation is required.

This research is supported by UWA and DPIRD.

Rows of 'bug dorms' in the UWA Plant Growth Facility.



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], Dr 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], Sun Kumar Gurung[1], Audrey Tascon[1]

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

This project is exploring the use of black soldier flies (BSF) to turn livestock wastes into useful products. The overall objective is to develop high quality soil conditioners and fertilisers from manures and other wastes though innovative technologies using BSF – a non-invasive, non-pest fly species for waste management.

Using BSF technology to convert livestock wastes into beneficial end products will not only allow Australia's livestock industries to 'close the loop' on their organic wastes and reduce the associated biosecurity and environmental risks but will also contribute significantly to improving the sustainability of Australian agriculture.

During 2021, the multidisciplinary research team have been working across a wide spectrum of research activities, including undertaking optimisation trials on various waste streams, conducting pot trials, exploring the biocontrol mechanism for stable flies and pathogens, seeking stakeholder consultation, and undertaking field trials to develop a BSF-based soil improver for crops.

Through industry-based articles, conferences, radio programs, and a live ABC News broadcast on primetime television, the team are promoting the research activities and keeping the agricultural industry informed and anticipating the research outcomes.

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.

A photo of black soldier fly larvae.

The manures frass experiment 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), Michal Zawierta[1], Dr Hemendra Kala[1], Dr Andrew Guzzomi[1], Jamir Khan[1] (team leader), Robert Crew[1], Shami Mohdar[1], Brodie Dewar[1], Thehara Sumanarathna[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 Research Theme, and the Microelectronics Research Group at the School of Engineering. At the end of 2021, the team is nearing completion of its first prototype hexacopter drone for test flights at the UWA Shenton Park Field Station.

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

Mohammed Bennamoun[1], (project co-leader;

Telstra tower deployment at UWA Farm Ridgefield

Project team: Dr Dilusha Silva[1] (project leader; dilusha.silva@uwa.edu.au), Associate Professor Gino Putrino[1], Emeritus Professor Graeme Martin[1], Ron Jones[1], Craig Williams[1]

Collaborating organisations: [1]UWA; Uni IT; UWA Campus Management

The lack of effective network connectivity on UWA Farm Ridgefield has so far hindered it in its mission of showcasing the farm of the future. Many of the latest technologies rely on data, on-farm interconnectivity, and connectivity to external services. To this end, a team of IOA members with support from Uni IT and Campus Management have over the last four year pursued various options of providing 4G mobile coverage and high-bandwidth internet connectivity to UWA Farm Ridgefield. This work culminated in the completion of a Telstra mobile phone tower on the farm in early July 2021.

This research is supported by UWA.

The completed Telstra tower on UWA Farm Ridgefield.

Machine learning for climate-change-ready crops

Project team: Professor David Edwards[1] (project co-leader; dave.edwards@uwa.edu.au), Professor MohammedBennamoun[1],(projectco-leader; mohammed.bennamoun@uwa.edu.au), Dr Philipp Bayer[1], Professor Jacqueline Batley[1], Dr Steve Marcroft[2], Associate Professor Alex Idnurm[3], Professor Angela van de Wouw[3], Monica Danilevicz[1], Robyn Anderson[1], Professor Farid Boussaid[1], Dr Saqib Ejaz Awan[1], Wijayanti Nurul Khotimah[1]

Collaborating organisations: [1]UWA; [2]Marcroft Grains Pathology; [3]University of Melbourne

A collaboration led by UWA brought machine learning, a form of artificial intelligence, to the field as part of two GRDC-funded projects. The first project used field images taken using unmanned aerial vehicles (drones) for the detection of crop stress, enable early detection and mapping of stress factors including frost and disease. The project collated large amounts of multispectral image data from industry and public repositories, allowing the building of machine learning models to identify stress and predict yield across a range of crops and environments relevant to Australia.

The second project applied machine learning to better understand the interaction between canola and its pathogen *Leptosphaeria maculans*, the cause of devastating blackleg disease. Project researchers trained artificial neural networks to associate genome variation data with blackleg resistance phenotypes to identify non-additive genetic effects of blackleg resistance that cannot be easily identified using standard multivariate statistical models. A large amount of data is required to train neural networks, so the team joined up with public and commercial partners in Australia and Europe to secure data access.

These projects will deliver value to Australian growers by supporting advanced approaches for crop management as well as the development of varieties with improved stress tolerance and disease resistance.

This research is supported by UWA and GRDC.

Blackleg in canola stem, caused by the pathogen *Leptosphaeria maculans*.

The application of infrared spectroscopy for on-site wheat grain analysis and varietal identification

Project team: James Kelly[1], Dr Nicolas Taylor[1] (project leader; nicolas.taylor@uwa.edu.au), Dr Björn Bohman[1], Dr Dion Bennett[2]

Collaborating organisations: [1]UWA; [2]Australian Grain Technologies; InterGrain

Current methods for measuring wheat quality and identifying wheat varieties involve costly and time-consuming processes such as dough rheology testing, mass spectrometry, HPLC and gel electrophoresis. There is a significant interest in the Australian wheat industry for developing non-destructive, field based, rapid varietal confirmation and dough quality assessment methods for breeding lines. This project aims to investigate the application of FTIR spectroscopy combined with predictive models using multivariate analysis for on-site wheat grain analysis of Australian varieties to allow farmers and breeders to rapidly identify varieties and assess dough-making quality of breeding lines.

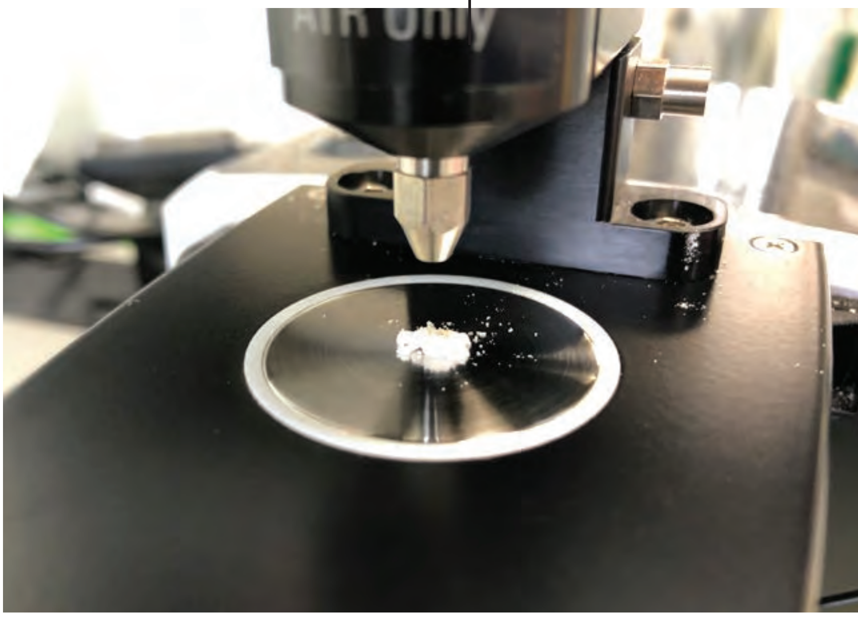
This research involves utilising FTIR spectroscopy to measure the infrared spectrum of flour for hundreds of Australian wheat lines supplied by wheat breeding companies with varying end-product quality, progeny and harvest locations. By utilising multivariate analytical techniques including partial least squares regression (PLSR) and linear discriminant analysis (LDA), prediction models can be constructed to predict multiple dough qualities including protein content, extensibility and water absorption, as well as classify flour samples according to their variety and location they were harvested. With further optimization, this technology has the potential to streamline the current processes for measuring wheat quality and classifying wheat lines.

Over the past 12 months, the classification and quality assessment regression models have been optimised through the further acquisition of grain and flour samples. PLSR models were constructed that could accurately predict multiple dough qualities including protein content, extensibility and water absorption, as well as roughly predict R-max (dough strength). Research over the past year also showed that LDA could classify samples originating from five different locations across Western Australia as well as perform an accurate pairwise variety classification for multiple Australian wheat variety pairs. By optimizing the regression models constructed using PLSR, implementation of FTIR spectroscopy in the early stages of the wheat breeding process can assist wheat breeders in culling poor quality wheat lines and choosing high quality wheat lines for late stage dough rheology analysis. The accuracy seen with the LDA classification models also suggested that field based portable FTIR spectroscopy could provide a means for growers to carry out rapid on-site varietal confirmation and quality assessment for specific wheat types and reduce the time and costs required for the current standard techniques.

This research is supported by the UWA RTP Scholarship and GRDC Research Scholarship.

PhD researcher James Kelly examining wheat grain.

A wheat flour sample ready for infrared analysis.



A farmer using an electronic tablet in his rice field.

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 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 2021. Our research focus contributes to the realisation of the 2030 Agenda of Sustainable Development.

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The economic and social contribution of the Western Australian CME sector

Project team: Winthrop Professor Tim Mazzarol[1] (project leader; tim.mazzarol@uwa.edu.au), Winthrop Professor David Gilchrist[1], Associate Professor Andrea Gaynor[1], Emeritus Professor Geoffrey Soutar[1], Dr Amin Mugera[1], Dr Bruce Baskerville[1], Peter Wells[2]

Collaborating organisations: [1]UWA; [2]Co-ops WA; Business Council of Co-operatives and Mutuals; Burgundy School of Business, Dijon France; Co-ops New Zealand

The first co-operative in Western Australia was founded in Albany in 1868. Since then, co-operative and mutual enterprises have played a significant role in the development of the state. The evolution of the WA Co-operative and Mutual Enterprise (CME) sector was different from other states. Today, although comprising only 5.3 per cent of the total CMEs in Australia, it has many of the largest and most successful firms. This study examines the unique aspects of the historical evolution of the WA CME sector, and its contribution to the state's economic and social development. It also examines the lessons that this offers for existing and future CMEs and the role of government policy and regulation in shaping both the past and the future.

This research is supported by the ARC, Co-operative Bulk Handling Group Ltd., Capricorn Society Ltd., Co-operatives WA, Mt Barker Co-operative Ltd., United Crate Co-operative Ltd., Wesfarmers Ltd., RAC WA, and York and Districts Co-operative Ltd.

Adoption of laser-land leveller technology in the irrigated farmlands of Punjab, Pakistan

Project team: Asjad Tariq Sheikh[1], Dr Amin Mugera[1](project leader: amin.mugera@uwa.edu.au), Associate Professor Ram Pandit[1], Associate Professor Michael Burton[1]

Collaborating organisations: [1]UWA; International Food Policy Research Institute (IFPRI)

Governments and international donors are actively promoting laser-land leveller (LLL) technology to produce environmental benefits (i.e., avoid soil salinity, minimise soil erosion risk, and groundwater security) that could lead to sustainable agricultural production and averting land degradation. We investigated the adoption process of laser-land leveller technology in Punjab, Pakistan using survey data from 504 farming households. We focused on the factors that could influence the speed of adoption.

We found that about 70 per cent of the surveyed households had adopted the technology, and the average time to adoption was nine years. The critical determinants of the speed of adoption include strong legal land entitlements, farm size, and farm location along the watercourse. Information acquired through formal and informal sources and exposure to the technology potentially reduce adoption time. Adopting the technology reduced groundwater use by about 23bout 23 per cent in wheat crop. These results highlight the importance of institutional arrangements such as the provision of agricultural extension services, increasing of exposure to technology, and establishment of legal property rights over land in enhancing the speed of uptake of LLL technology.

This research is supported by IFPRI.

A Landking laser land leveller pictured in a field in India.

Assessing adoption and diffusion of agricultural innovations in Bangladesh

Project team: Hackett Professor Kadambot Siddique[1], Dr Amin Mugera[1] (project leader: amin.mugera@uwa.edu.au), Professor Nazrul Islam[2], Dr Gour Gobinda Goswami[2], Professor Mohammed Quaddus[3], Dr Fazlul Rabbanee[3], Dr Elizabeth Jackson[3], Professor Dr M Zulfikar Rahman[4]

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

Bangladesh has the highest population density in the world. Like many developing countries, most people are employed directly or indirectly in the agriculture sector. Improving the agricultural productivity of crops and livestock through the adoption and diffusion of local and imported innovations is critical for reducing rural poverty and improving the economic well-being of key stakeholders in the agribusiness value chains. Recognizing that agricultural technology is the basis for sustainable agricultural growth, the Government of the Peoples' Republic of Bangladesh, in conjunction with other international development agencies, has invested considerable resources in agricultural research and development. However, the adoption of agricultural innovations, particularly those based on indigenous knowledge, remains low and the speed of diffusion is slow. Despite this, there is a lack of systematic studies that can inform policymakers and management practitioners on what innovations are preferred by both subsistence and commercial farmers and appropriate action to overcome the bottlenecks of low and slow adoption of available innovations.

A multidisciplinary team of researchers from Bangladesh's premier private university, the North-South University, and Bangladesh National University collaborated with Australian researchers from The UWA Institute of Agriculture and Curtin University wrote a two-year joint research proposal on adoption of agricultural innovations. The project aims to identify the bottlenecks in the adoption of local and imported agricultural innovations by smallholder producers and other value chain participants in Bangladesh. The research team will explore managerial and policy interventions that can enhance the speed and adoption of agricultural innovations that are deemed to have high impact in improving the welfare of smallholder producers and other value chain participants.

This research is supported by the Krishi Gobeshona Foundation.

An elderly man working on a farm in Bangladesh.

Overseas labour migration: Its 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 Maria Fay Rola-Rubzen[1], Associate Professor Ram Pandit[1]

Collaborating organisation: [1]UWA

Overseas migration of Nepalese youth for labour employment has increased exponentially over the past decade. An outflow of the most productive labour force has resulted in a huge inflow of remittances and contributed to poverty reduction significantly. Along with the large-scale overseas migration, Nepal is also increasingly witnessing a substantial return migration. However, factors influencing migration decisions, occupational choice of returnee migrants, and impacts of migration on smallholder farm-households are not yet adequately understood. Therefore, this study aimed at examining the factors that influence overseas migration, migration intensity and destination choice of the migrants, factors that influence return migration, and occupational choice of returnees, including migration impacts on household welfare and agricultural production and incomes. For this study, we collected primary data from 708 households (i.e., 242 current overseas migrants, 267 returnee migrants and 198 non-migrant households) from Chitwan (terai/plain region) and Kaski district (hill region) of Nepal.

The results suggest a higher propensity and intensity of overseas migration in households that have higher proportion of educated members, migration networks located in the hills and an opposite effect in households having employed members and higher asset index. Furthermore, individuals with higher education, older heads or higher wealth status are more likely to choose wealthy Western and Asian countries as migration destinations. Similarly, results suggest a higher propensity of return among those who are married, household heads, work in labour destinations such as Malaysia and Gulf countries and have made productive investments at home. Whereas individuals with higher education, previous migration experience, longer overseas stay duration, and employment in skilled labour sectors are less likely to return. Additionally, returnees with a higher education, higher accumulated income overseas are more likely to be entrepreneur whereas those who return due to compelling reasons and have a larger farm size at home are more likely to be self-employed after return. The impact analysis of migration on household welfare and agricultural production and incomes in underway. Moreover, the findings related to migration decisions and occupational choice of returnee migrants have policy implications on regulating overseas migration as well as organizing productive reintegration of returnee migrants in Nepal.

This research is supported by UWA.

Conducting a focus group discussion in Chitwan district, Nepal.

Interviewing a female respondent in Chitwan district, Nepal.

Researcher Eric Wilson with smallholder farmer in Cambodia.

Forages for livestock: Understanding the economic benefit of labour savings created by forage adoption

Project team: Eric Wilson[1], Dr Amin Mugera[1] (project leader; amin.mugera@uwa.edu.au), Dr Davina Boyd[2]

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

High rates of rural outward migration in Cambodia have resulted in rural labour supply shortages and rising labour costs. Labour saving agricultural technologies can help Cambodian smallholders adapt to labour shortages. Forages can be grown by cattle owning smallholders to reduce the time required to collect feed for livestock. This study used a cross-sectional mixed methods survey designed to: 1) estimate the effect of forage adoption on the amount of labour required for cattle production activities; and 2) understand the impacts that the labour-saving benefits of forage adoption have at a household level. An endogenous switching regression model was used to calculate the effect of forage adoption on the labour required for cattle production activities. An investment analysis was used to estimate the economic impact of forage adoption in terms of the labour-saving benefits produced by forage adoption at a household level.

Although previous studies have identified a labour-saving benefit associated with forage adoption and the social benefits of these labour savings studied, the economic impact of these labour savings at a household level is yet to be examined. Moreover, exploring the impacts of forage adoption in terms of labour savings is important as forage adoption may not necessarily lead to productivity benefits, such as, improved cattle performance.

On average, forage adoption reduced the labour requirement of cattle production by 8.825 per cent. The household head was the main beneficiary of the time savings, allocating their time saving between rest and relaxation and working either around the house, on-farm or off-farm. By adopting forages, a household could reduce their overall household labour requirement by an average of 16.5 days per year at an economic cost of $53.28 per year. However, for a household to economically breakeven, over 52 per cent of saved time needs to be used working off-farm

The overall economic benefit of forage adoption, in terms of labour savings, is sensitive to how saved time is used and suggests forages are not suitable for all cattle owning households. Forages do, however, remain a valuable tool to improve the livelihoods of cattle owning smallholders and assist with the development of the Cambodian cattle industry, especially if the trend of rural outward migration continues and the price of labour continues to rise. Given forages may not be suitable for all households, it is recommended that government agencies and research and extension projects consider targeting farmers with the resources to invest in and benefit from forage technologies. To ensure the forage technologies being developed and promoted are meeting the needs of Cambodian smallholders, further research is needed to understand the factors which are limiting forage adoption.

This research is supported by ACIAR.

Truck for transporting farm produce to market in Cambodia.

Market participation and intensity by smallholder maize producers: Evidence from Zambia

Project team: Mario Kabuswe Changala[1], Dr Amin Mugera[1] (project leader; amin.mugera@uwa.edu.au)

Collaborating organisation: [1]UWA

Access to functional and viable markets is necessary and crucial in uplifting rural livelihoods from poverty through increased incomes generated from participation in markets. Despite this, smallholder maize market participation in Zambia is still low. Smallholder participation in the maize market is much lower despite government intervention through various policy instruments. This study employed statistical methods to jointly estimate maize market participation decisions and intensity among rural households in Zambia by analyzing the Rural Agricultural Livelihoods Survey for 2015 (RALS 2015).

The key findings of the research are that farm household characteristics influencing production and transaction costs are more relevant in explaining smallholder maize market participation and intensity rather than price incentives. The factors found to determine both market participation and intensity of participation include the quantity of maize harvested, fertiliser application, access to subsidised inputs, access to credit, household size, and age of the household head. Other factors that only affect market participation include education of household head, membership to a farmers group and farm location. Transport cost only influenced the intensity of participation, and ownership of means of transport only influenced market participation. The results imply that policy interventions should focus on increasing marketable output among smallholder farmers and reducing regional disparities through group marketing rather than on fixing selling price above market clearing price. Provision of soft skills to farmer groups and cooperatives in marketing can help reduce transaction costs and encourage collective bargaining through pooled resources. Provision of extension services that aim at improving land productivity through agronomic training should be supported.

This research is supported by the Africa Award Scholarship from the Department of Foreign Affairs and Trade.

Dried maize on the cob hanging in a market.

What drives market participation and intensity of sales and purchases? Evidence from smallholder maize-legume producers in Kenya

Project team: Wilckyster Nyateko Ogutu[1], Dr Amin Mugera[1] (project leader; amin.mugera@uwa.edu.au), Associate Professor Atakelty Hailu[1]

Collaborating organisation: [1]UWA

This study investigated the factors that influence smallholder maize-legume producers in Kenya to participate in output markets as either sellers or buyers and their intensity of participation. Analysis is based on repeated household survey data collected in 2011, 2013 and 2015. A double-hurdle model that incorporates a correlated random effects procedure was used to control for unobserved heterogeneity and potential endogeneity. The study finds an inverse relationship between the probability of participating in the market as a buyer and farm output and a positive relationship with household size. In the event of market participation, a positive relationship is found between distance to market and volumes of purchases. The probability of market participation as a seller is reduced by incidences such as drought, disease infestation, and waterlogging and increased by farm output and household wealth. The intensity of sales is positively associated with farm output, household wealth, on-farm occupation, education of household head and social capital and negatively associated with incidence of disease infestation and livestock units.

This study highlights the importance of promoting smallholder policy interventions that create a conducive working environment to enable households increase wealth, particularly farm machinery, to increase production. Likewise, policies interventions should focus on educating farmers about risk mitigation strategies for production shocks to control their negative effects on market participation.

This research is supported by ACIAR through the John Allwright Fellowship Program.

A fresh food market stall in Mombasa, Kenya.

What benchmarking metric to use when evaluating firm productivity and viability?

Project team: Steele West[1], Dr Amin Mugera[1] (project leader; amin.mugera@uwa.edu.au), Professor Ross Kingwell[1,2]

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

The conventional technical efficiency measures are widely used to evaluate and benchmark the performance of firms in the same industry. This is important for providing policy suggestions on how to improve performance and increase both viability and competitiveness. However, a limitation of conventional technical efficiency measures is that they evaluate the performance of a decision-making unit in an explicit direction relative to the best-practice frontier and not the most productive point on the frontier. Therefore, the measure does not provide policy insight on how to direct decision-making units to achieve the best possible productivity level.

Taking a departure from conventional nonparametric benchmarking studies, this study evaluated and benchmarked the performance of commercial farm businesses in the Western Australia's wheatbelt region using an alternative metric called total factor productivity efficiency ('TFP efficiency') and compared the results to those obtained using the conventional technical efficiency measures. The study found the two measures to differ in ranking the performance of decision-making units and the main drivers of firm heterogeneity. Therefore, policy insights that are drawn from results may also differ. This is an important insight that policymakers and practitioners need to be aware of.

This research is supported by UWA.

Is traditional rice reviving? An exploratory study in Kerala, India

Project team: Professor Jayasree Krishnankutty[2] (project leader; jayasree.krishna@kau.in), Winthrop Professor Michael Blakeney[1], Rajesh Raju[1], Hackett Professor Kadambot Siddique[1]

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

Traditional rice systems are holistic systems, resilient, eco-friendly and a key to nutrition security but unfortunately, in decline. Traditional cultivation that uses local rice varieties appears to withstand the impacts of climate change. Many agencies in rice producing countries are working towards the revival of traditional rice varieties.

This study explored the traditional rice farming scenario in Kerala, India. The research team looked at the farmers who cultivated traditional rice varieties, their satisfaction levels and what factors would lead to the sustainability of traditional rice cultivation. The study found some emerging types of new rice farmers who were more satisfied with traditional rice cultivation. Marketed surplus, education, area, and institutional support were identified as the key factors that lead to successful farm enterprises. While there were positive indicators for the sustainability of traditional rice, how far they will endure in the future is unclear.

The results from this study may be relevant to rice farming communities of other Asian countries, as the ongoing structural transformation is similar in those countries. In any case, focused policy interventions and a well-defined legal back-up are essential for sustaining traditional varieties and their advantage for posterity.

Sustainability of traditional rice cultivation in Kerala, India – A socio-economic analysis

Project team: Professor Jayasree Krishnankutty[2], Winthrop Professor Michael Blakeney[1] (project leader; michael.blakeney@uwa.edu.au), Rajesh Raju[1], Hackett Professor Kadambot Siddique[1]

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

Traditional rice cultivars and cultivation are on the decline in most rice-growing areas, mainly because of their low productivity. Packed with nutritionally, environmentally and locally superior qualities, traditional cultivars hold the key for sustainability in rice cultivation.

This study explored the dynamics of traditional rice cultivation in Kerala, India. It examined the economic, institutional and socio demographic factors involved in the production and marketing of traditional rice. We employed a multinomial logit model and discriminant function analysis to extract the key factors governing farmers' marketing behaviour, and various cost measures to study the economics of rice enterprises. The socio-demographic factors were analysed using descriptive statistical tools. Holding size and institutional support were the main factors governing the marketing behaviour of farmers.

Even though traditional rice farming was not found to be cost-effective in implicit terms, it was remunerative when imputed personal labour and owned land costs were not considered. The study found that traditional farmers are ageing, have a lower education and use limited marketing channels. However, most of them were satisfied with their farm enterprise. By streamlining the market support mechanism and processing facilities, traditional rice would gain momentum in key areas.

This research is supported by the ARC.

Traditional cultivars hold the key for sustainability in rice cultivation.

Impacts of protected area policy on household income: Evidence from Chitwan National Park, Nepal

Project team: Pratikshya Kandel[1], Associate Professor Ram Pandit[1] (project leader; ram.pandit@uwa.edu.au), Associate Professor Benedict White[1]

Collaborating organisations: [1]UWA; Department of National Parks and Wildlife Conservation, Nepal

Providing incentives to local communities to mitigate the negative impacts of conservation interventions is central to the mission of many conservation policies. Yet, the empirical evidence is limited on the effectiveness of such incentive-based conservation interventions on household welfare. In this study, we evaluated the impact of Protected Area policy, particularly the buffer zone policy, of providing conservation-incentives to local communities to increase their household income in the buffer zone areas – areas adjoining to protected areas. Using a case of Chitwan National Park in Nepal, we evaluated the economic impacts of the buffer zone policy in three ways: Firstly, we investigated the impacts of living in buffer zone areas on household income by comparing with the credible counterfactuals outside the buffer zones. Secondly, we examined the impacts of the alternative income generating trainings on household income and thirdly, we estimated the impacts of tourism development trainings on household income.

We collected household-level data from buffer zone and the surrounding areas outside the buffer zone of Chitwan National Park in October to December 2020. We conducted five focus group discussions and surveyed 728 households to collect quantitative and qualitative data. We used a quasi-experimental research design and Propensity Score Matching technique to evaluate the economic impacts of the buffer zone policy on local communities.

Our findings showed that buffer zone policy does not adversely affect the local economic outcomes. Moreover, it suggests that households living inside the buffer zone enjoy a greater level of per capita household income (up to 19 per cent) than compared to households living in adjacent areas outside the buffer zone. In addition, our results demonstrate that income-generating training has no observable impacts whereas tourism development training has significant positive impacts (up to 52 per cent) on household income. Our study suggests that environmental conservation does not necessarily come at the expense of local communities, and conservation interventions, if designed appropriately, can be an effective tool for delivering conservation goals whilst benefiting local communities.

This research is supported by the Australian Government RTP Scholarship and University Postgraduate Award.

A traditional homestay in the buffer zone area in Chitwan National Park.

An enumerator conducting a household survey in Chitwan National Park buffer zone area.

PhD candidate Tshering Samdrup in Dochula, Bhutan.

Understanding the determinants of smallholder participation in contract farming: Case study of hazelnuts farming in Bhutan

Project team: Tshering Samdrup[1] (project leader; tshering.samdrup@research.uwa.edu.au), Associate Professor James Fogarty[1], Dr Sayed Iftekhar[1], Dr Ram Pandit[1], Dr Kinlay Dorjee[2]

Collaborating organisations: [1]UWA; Royal University of Bhutan, Bhutan

UWA PhD candidate Tshering Samdrup was awarded the Australian Agricultural and Resource Economics Society Crawford Fund grant to assist with his thesis, which aims to provide an in-depth understanding of the link between foreign direct investment (FDI), contract farming, and food security in developing countries.

Investment in agriculture is an important and effective strategy to enhance agricultural productivity, reduce poverty and achieve food security. With limited funds available, the governments of developing countries are increasingly turning to FDI to plug their investment shortfall. Although there is positive relationship between FDI and economic growth, the relationship between FDI and food security is less clear.

The research project includes a case study of the largest FDI in Bhutan to date: hazelnut farming. The venture is intended to generate the income of smallholder farmers, help convert fallow lands into thriving orchards and help regenerate the environment. Many Bhutanese farmers started cultivating hazelnut trees on their farms but are yet to earn steady and stable income from the nuts.

This research is supported by UWA and the Crawford Fund.

The hazelnut (*Corylus avellana*) is a member of the birch family of trees.

Understanding farm-household management decision-making for increased productivity in the Eastern Gangetic Plains

Project team: Associate Professor Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Dr Roy Murray-Prior, Jon Marx Sarmiento[1], Bibek Sapkota, Dr Renato Villano[2], Dr Md Farid Uddin Khan[3], Dr Bijoy Krishna Banik[3], Dr Md Abdur Rashid Sarker[3], Dr Md Elias Hossain[3], Dr Murshida Ferdous Binte Habib[3], Dr Rejaul Karim Bakshi[3], Md Istique Asif[3], Dr Tapan Kumar Karmaker[4], Md Mamunur Rashid[4], Mohammad Enamul Kabir[4], Most Mazbahun Nahar[4], Mohammad Abdur Rahman[4], Ashish Kumar Mojumdar[4], Md Mahafuj Alam[4], Priyanka Akkar[4], Dr Ram Datt[5], Dr Ranvir Kumar[5], Dr S M Rahaman[5], Dr Sanjay Kumar[5], Shubhi Chaurasia[5], Dr Kalyan K Das[6], Dr Abhash Kumar Sinha[6], Dr Apurba Kumar Chowdhury[6], Dr Arunava Ghosh[6], Dr Biplab Mitra[6], Dr Deepa Roy[6], Dr Prateek Madhab Bhattacharya[6], Dr Tapamay Dhar[6], Ms Achyoung Lepcha[6], Mr Subhankar Sarkar[6], Dr Yuga Nath Ghimire[7], Namdev Upadhyay[7], Dr Krishna Prasad Timsina[7], Samaya Gairhe[7], Yogendra Acharya[7], Hema Kumari Poudel[7], Surya Prasad Adhikari[7]

Collaborating organisations: [1]UWA; [2]University of New England, NSW; [3]Rajshahi University, Bangladesh; [4]Rangpur Dinajpur Rural Service Bangladesh; [5]Bihar Agricultural University, India; [6]Uttar Banga Krishi Vishwavidyalaya, India; [7]Nepal Agricultural Research Council

This project's overall aim is to improve the productivity, income, and food security of smallholder farming households in the Eastern Gangetic Plains (India, Nepal, and Bangladesh). The key research objectives are to determine whether behavioural economics can provide insights on how to diffuse promising technologies such as conservation agriculture at a faster rate, and to identify the specific behaviours and bottlenecks leading to or constraining the adoption of conservation agriculture (CA).

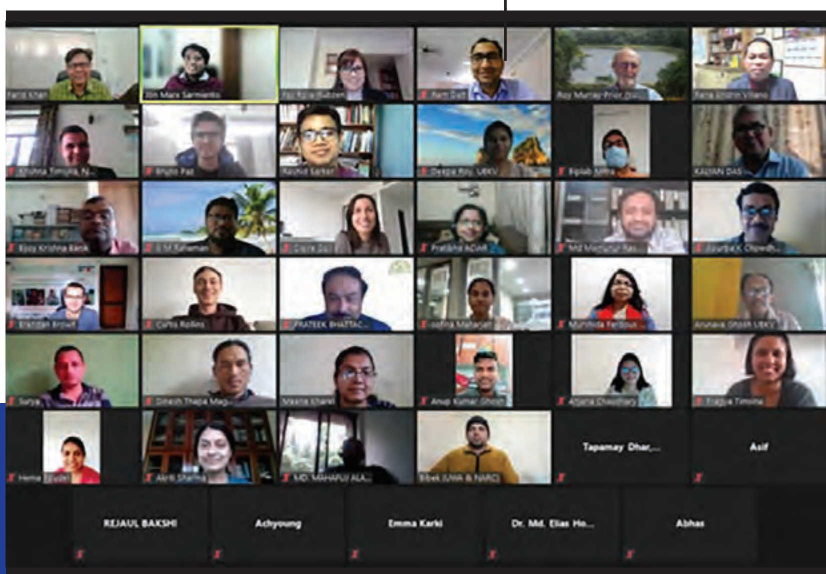
A highlight of the project thus far is the meaningful qualitative data collected from 369 *Key Informant Interviews* and 31 *Focus Group Discussions,* which comprised of 301 farmers and 50 service providers. There was a lot of positive feedback from ACIAR regarding the compelling insights that were emerging; such as the non-economic factors that played a crucial role in farmers' decision-making and a clear opportunity to inform more effective intervention strategies in supporting CA adoption.

During 2021, the project team has been testing the data through behaviour experiments in the four case study regions. All partner organisations completed the baseline surveys and behavioural experiments averaging 600 respondents per case study. Research teams designed and tested several interventions, including nudging via reminders and message framing, to test the effectiveness in increasing farmers adoption of CA technologies.

This research is supported by ACIAR.

This project is focused on smallholder farming households in the Eastern Gangetic Plains of India, Nepal and Bangladesh.

Screengrab of a Zoom meeting held between members of the international research team in 2021.



Socio-cognitive constraints and opportunities for sustainable intensification in South Asia: Insights from fuzzy cognitive mapping in coastal Bangladesh

Project team: Associate Professor Sreejith Aravindakshan[2,3] (project leader; sreejith.aravindakshan@wur.nl), Dr Timothy Krupnik[3], Sumona Shahrin[2,3], Dr Pablo Tittonell[4,5], Hackett Professor Kadambot Siddique[1], Lenora Ditzler[2], Dr Jeroen Groot[2,3,6]

Collaborating organisations: [1]UWA; [2]Wageningen University, The Netherlands; [3]CIMMYT, Bangladesh; [4]Instituto Nacional de Tecnología Agropecuaria, Argentina; [5]Groningen University, The Netherlands; [6]Bioversity International, Italy

Appreciating and dealing with the plurality of farmers' perceptions and their contextual knowledge and perspectives of the functioning and performance of their agroecosystems – in other words, their 'mental models' – is central for appropriate and sustainable agricultural development.

In this respect, the sustainable development goals (SDGs) aim to eradicate poverty and food insecurity by 2030 by envisioning social inclusivity that incorporates the preferences and knowledge of key stakeholders, including farmers. Agricultural development interventions and policies directed at sustainable intensification (SI), however, do not sufficiently account for farmers' perceptions, beliefs, priorities, or interests. Considering two contrasting agroecological systems in coastal Bangladesh, we used a fuzzy cognitive mapping (FCM)-based simulation and sensitivity analysis of mental models of respondents of different farm types from 240 farm households.

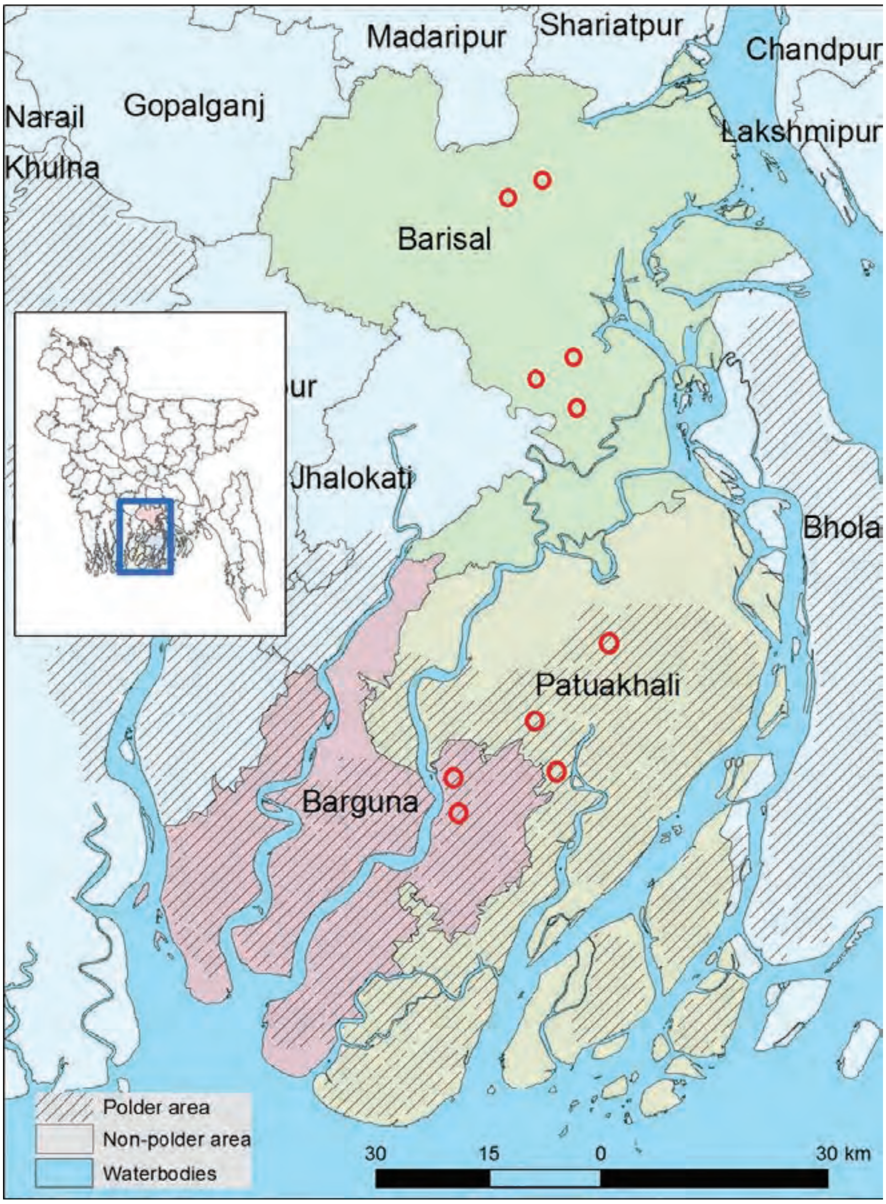
The employed FCM mental models were able to:

- Capture farmers' perception of farming system concepts and relationships for each farm type, and
- Assess the impact of external interventions (drivers) on cropping intensification and food security.

We decomposed the FCM models' variance into the first-order sensitivity index (SVI) and total sensitivity index (TSI) using a winding stairs algorithm. Both within and outside polder areas, the highest TSIs (35-68 per cent) were observed for the effects of agricultural extension on changes in other concepts on the map, particularly food security and income (SI indicators), indicating the importance of extension programs for SI. Outside polders, drainage and micro-credit were also influential; within polders, the availability of micro-credit affects farmer perceptions of SI indicators more than drainage. This study demonstrated the importance of reflection on the differing perspectives of farmers both within and outside polders to identify entry points for development interventions. In addition, the study underscores the need for micro-farming systems-level research to assess the context-based feasibility of introduced interventions as perceived by farmers of different farm types.

This research is supported by the United States Agency for International Development, Bill & Melinda Gates Foundation, and the Foundation Stiftung Fiat Panis (Germany).

Map of the study districts showing the location of surveyed farmer communities, denoted by red circles.



The Australian Co-operative and Mutual Enterprise Index (ACMEI)

Project team: Winthrop Professor Tim Mazzarol[1] (project leader; tim.mazzarol@uwa.edu.au), Karl Coombe[2], Anthony Taylor[2], Melina Morrison[2]

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

The ACMEI report has been undertaken since 2014 and is a longitudinal study of the co-operative and mutual enterprise (CME) sector in Australia. It is undertaken in conjunction with the Business Council of Co-operatives and Mutuals (BCCM) and provides the baseline data for the annual National Mutual Economy Report. This study collects financial and non-financial data for all CMEs in Australia and generates a Top-100 largest CMEs league table, as well as examining trends in the growth, decline and performance of the sector. Case studies of selected CMEs are included in each report.

This research is supported by the BCCM.

The BCCM is the peak body for co-operatives and mutuals in Australia.

The social and economic history of the Royal Automobile Club of WA

Project team: Winthrop Professor Tim Mazzarol[1] (project leader; tim.mazzarol@uwa.edu.au), Dr Bruce Baskerville[1]

Collaborating organisations: [1]UWA; BCCM; RAC WA

This study examines the history of the Royal Automobile Club (RAC) of WA from 1905 to 2020. It examines the impact of the RAC WA on the development of WA's motoring industry, use of motor vehicles, and development of the state's road systems, road safety and environmental impacts of the motor car. The history traces the development of the state and the motor vehicle showing the pivotal role played by the RAC WA as a member-focused, mutual enterprise.

This research is supported by RAC WA.

A Royal Automobile Club of WA motorcycle. Photo: Winthrop Professor Tim Mazzarol.

COVID-19 and tourism: An update

Project team: Dr David Vanzetti[1] (project leader; david.vanzetti@uwa.edu.au), Dr Ralf Peters[2]

Collaborating organisations: [1]UWA; [2]United Nations Conference on Trade and Development

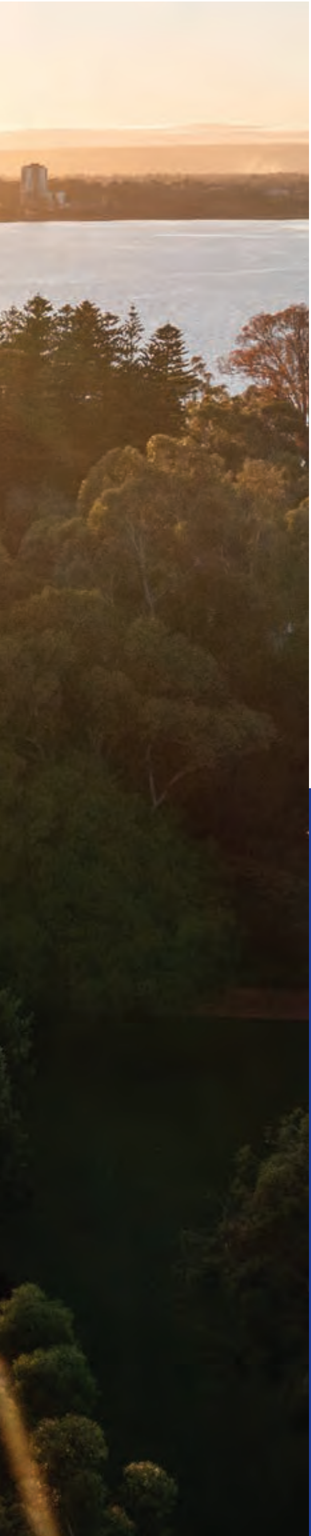
Tourism is one of the sectors most affected by the COVID-19 pandemic. Indeed, the number of international tourist arrivals worldwide declined by 84 per cent between March and December 2020 compared with the previous year, according to data observed by UNWTO. Based on a range of tourist arrivals' projections, the report quantifies the potential economic effects of the contraction in tourism in 2021.

For a global snapshot, this research report assessed data from approximately 33 developed and (tourism-dependent) developing countries, including Australia; as well as Western, Eastern and Southern Africa, the South African Customs Union, and remaining regions. The indirect effects of the pandemic were found to be significant. Due to linkages with upstream sectors such as agriculture, a drop in tourist sales leads to a 2.5-fold loss in real GDP, on average, in the absence of any stimulus measures. Based on three scenarios, one optimistic, one pessimistic and one where the asymmetric speed of vaccinations is considered, the economic losses could range between $1.7 trillion and $2.4 trillion worldwide in 2021. The results highlight the importance of the vaccine rollout in getting global tourism restarted and other mitigating measures.

This research is supported by UNCTAD and the World Tourism Organization.

The pandemic impacted the number of tourists coming to Australia to work on farms, such as picking oranges.

An aerial photo of UWA Crawley campus, with the sun rising over Matilda Bay.



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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 listeaning 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.

2021-2025

IOA received an overwhelmingly positive response to its Strategic Plan 2021-2025 when it was released in January. The Strategic Plan 2021-2025 was developed and refined over many months, including a full-day workshop in August 2020 attended by IOA partners and collaborators.

IOA Director Hackett Professor Kadambot Siddique said the comprehensive document would guide IOA to be future-focused, agile and sustainable. "As we look forward to the next decade, there is wide recognition that, while we have been successful to date, the world as we know it is fundamentally changing at such a rate that the status quo will no longer suffice," Professor Siddique said.

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 Reports and newsletters are also readily available to view and download.

In 2021, IOA's social media audience increased significantly. The IOA LinkedIn grew by 749 new followers to a total of 909. Five new event videos published to YouTube in 2021 amassed more than 1400 views. The @IOA_UWA Twitter presence near-doubled its growth from the previous 12 months, ending the year with approximately 1936 followers.

Newsletters

IOA's broad range of activities are regularly captured through its newsletter. It is an important channel through which IOA records and promotes its research outcomes, collaborations, recently-funded projects, staff and student achievements, upcoming events newly published peer-reviewed journal articles in agriculture and related areas. The newsletter audience includes key stakeholders, alumni, the agriculture industry, funding bodies, and members of the research community around the world.

Published three times per year – in April, August and December – the newsletter is circulated widely in electronic format and hardcopy to more than 5000 readers. Thirteen newsletter stories were republished as articles in newspapers *Farm Weekly* and the *Countryman* in 2021.

Strategic Plan

Front cover and inside spread of the April 2022 newsletter.

Hackett Professor Kadambot Siddique, Fiona Meaton, AgZero2030 chairman Simon Wallwork, Larissa Taylor and Ben White.

CSIRO and UWA researchers at the second joint meeting held at UWA.

Cara Peek and Hackett Professor Kadambot Siddique.

Visitors and guest lectures

Strict international, national and state border restrictions due to the COVID-19 pandemic meant that IOA was unable to welcome as many visitors as previous years.

These interactions were critical to knowledge sharing and strengthening research links and collaborations.

In February, IOA held a special seminar exploring the use of Magnetic Resonance Imaging (MRI) as a powerful tool for plant and agricultural research.

The seminar was led by National Imaging Facility Fellow Dr Tim Rosenow from the Centre for Microscopy, Characterisation and Analysis and held at Bayliss Lecture Theatre.

In April, The University of Sydney Associate Professor Simon de Graaf delivered the Alan Sevier Memorial Lecture on 'The future of sheep artificial breeding'.

Two joint speed seminars were held between IOA and CSIRO in order to explore latest research projects, discuss common interests and encourage future collaboration.

IOA partnered with AgZero2030 for an event to help drive the conversation around a carbon neutral future for WA agriculture.

More than 100 research, industry, and supply chain representatives gathered at The University Club of WA in October to collaboratively explore how to best navigate the net zero transition.

Just one day after accepting the prestigious national AgriFutures 2020 Rural Women's Award in October, IOA hosted Cara Peek for a special UWA lecture titled Disrupt for Good.

Stargazers enjoying the ICRAR telescopes on the oval.

Pingelly Astrofest

A crowd of more than 500 astronomy enthusiasts gathered at the Pingelly Recreation and Cultural Centre on 20 March for the 2021 Pingelly Astrofest.

IOA and the Shire of Pingelly collaborated to deliver the free, family-friendly astronomy festival.

Proudly supported by Lotterywest, 2021 Pingelly Astrofest attracted a constellation of stargazers both new and experienced – including locals and groups visiting from neighbouring towns and Perth.

This was the first year the event has been held at the Centre, after it was held at UWA Farm Ridgefield in 2016 and 2018.

Although Pingelly Astrofest quickly outgrew its original location, UWA Farm Ridgefield was still front-and-centre with a popular information stall and craft workshop led by one half of the farm management team Cathy McKenna.

"It was great to share information about the farm with curious visitors and also see lots of our neighbouring farmers and have a chat," Mrs McKenna said.

ICRAR set up their state-of-the-art telescopes on the oval and generously shared their passion for space with the community throughout the night.

IOA Director Hackett Professor Kadambot Siddique, who joined the Shire of Pingelly and Nyoongar elder Gary Bennell during the opening speeches and Welcome to Country, said the event was an outstanding achievement.

"Pingelly Astrofest is a true credit to excellent collaboration and hard work from the Shire, IOA and ICRAR," Professor Siddique said.

"It was a wonderful opportunity to enthuse youngsters about the role of science and technology."

The popular UWA SAgE stall entertained kids with hands-on experiments.

Professor Marco Fiorentini from UWA's School of Earth Sciences delighted visitors with the UWA Clarke Earth Science Museum collection including some of the oldest materials in the universe.

Visitors to the UWA Farm Ridgefield stall, led by Cathy McKenna.

Postgraduate Showcase presenters pictured with Professor Kadambot Siddique (far left), DPIRD Director General Ralph Addis (middle) and UWA Emeritus Professor Graeme Martin (far right).

Postgraduate Showcase: Frontiers in Agriculture

Seven of UWA's best and brightest postgraduate students in agriculture and related areas presented their research at the IOA's annual Postgraduate Showcase: Frontiers in Agriculture in June.

IOA Director Hackett Professor Kadambot Siddique welcomed the full house audience and introduced DPIRD Director General Ralph Addis.

Mr Addis delivered an optimistic opening address that emphasised the "very good environment of opportunity for clear, effective partnerships" between tertiary institutions, government and industry.

"We are starting to see some green shoots for the future," he said.

"We must work closely with our most-important partners to build our shared interests in a strong and deliberate way."

First session chair Professor Jacqueline Batley introduced the UWA School of Agriculture and Environment (SAgE) PhD candidate Tamsal Murtza.

Ms Murtza's research was focussed on the geographic and temporal patterns of a rapidly evolving plant pathogen causing white leaf spot disease in canola.

Fellow SAgE student Hira Shaukat then presented her research into using modern technology for quasi-3D field scale soil mapping.

By using "mobile, quick and inexpensive" electrical conductivity sensing, Ms Shaukat's research could help improve farm management decisions.

The School of Engineering student Wesley Moss captured the audience's attention with his presentation title: "The Need for Seed".

Mr Moss' research is focused on finding new solutions to increase the efficiency and sustainability of harvesting subterranean clover seed – and is currently investigating whether peanut harvesting machinery may be the answer.

SAgE postgraduate student Shilja Shaji delivered her research into the variability in physiological and production responses of heat stress in dairy cattle.

Following the afternoon tea break, second session chair Professor Shane Maloney introduced PhD candidate and DPIRD researcher Martin Harries.

Mr Harries explored his research investigation into biophysical constraints as drivers of land use change in the farming systems of South-West WA.

Juwita Dewi from SAgE then introduced the audience to her research into redox regulation of bud dormancy in grapevine.

Ms Dewi said her research would provide a better insight into control of bud burst using non-toxic and environmentally friendly compounds to improve yield.

The final speaker of the day was School of Molecular Sciences PhD candidate Clarisa Castaños, who presented her research into lipid metabolism in malnourished honey bees.

Industry Forum

Lucy Anderton, Jacinta Foley, Dr Terry Enright, Professor Kadambot Siddique, The Hon Alannah MacTiernan, Paul McKenzie, and Amanda and Bob Nixon.

Future-proofing WA agriculture: Maximising opportunities for a resilient food production system

How can we future-proof WA agriculture for the next generation and beyond?

This was the burning question on everyone's mind as they took their seats at The University Club of WA Auditorium on 21 July for IOA's 15th annual Industry Forum.

IOA Director Hackett Professor Kadambot Siddique said the much-anticipated forum attracted an audience of about 250 people.

"It was heartening to see so many members of the WA agriculture industry, research institutions and farming community coming together to share ideas and innovation for the future," Professor Siddique said.

"I was very pleased with the thought-provoking audience questions and passionate discussion that continued into the networking sundowner."

During her opening address, The Honourable Minister for Regional Development, Agriculture and Food and Hydrogen Industry Alannah MacTiernan MLC congratulated UWA on recently ranking number one in Australia and 16th in the world for Agricultural Sciences.

"That achievement is very impressive and very heartening," Ms MacTiernan said.

Keynote speaker Agrarian Management Principal Consultant Paul McKenzie set the tone of the forum with his assessment of how WAS can achieve a resilient grain production system.

He outlined six steps to achieve this goal: amend levy and End Point Royalty settings, reinvest in soil health, boost grain production, increase funding for research and development (R&D), encourage farmers to pay current and deferred costs and finally, restore the health balance sheet.

In a video recorded from NSW lockdown, KPMG Australia Food & Agribusiness Sector National Lead Georgie Aley encouraged the WA agriculture sector to "lead the dialogue" about sustainability targets.

Ms Aley said environmental, social and governance regulations were accelerating globally, and that local leaders needed to engage with government and drive constructive outcomes.

While growers have enjoyed an amazing start to the season, LA.One Economics and Consulting Principal Lucy Anderton cautioned against celebrating too soon.

The Albany-based broadacre farmer warned that complacency was "the enemy of resilience" and outlined three "bad habits" that farmers should avoid.

UWA Associate Professor Nik Callow explored the ways new spatial and drone technologies could be applied to WA agriculture in his video presentation.

Professor Callow featured an interview with DPIRD agricultural entomology research scientist Dr Severtson, who described how spatial technology can be used for scouting crop diseases.

Jasper Farms Technical Manager Jacinta Foley then took to the podium to present a case study on the Busselton avocado farm.

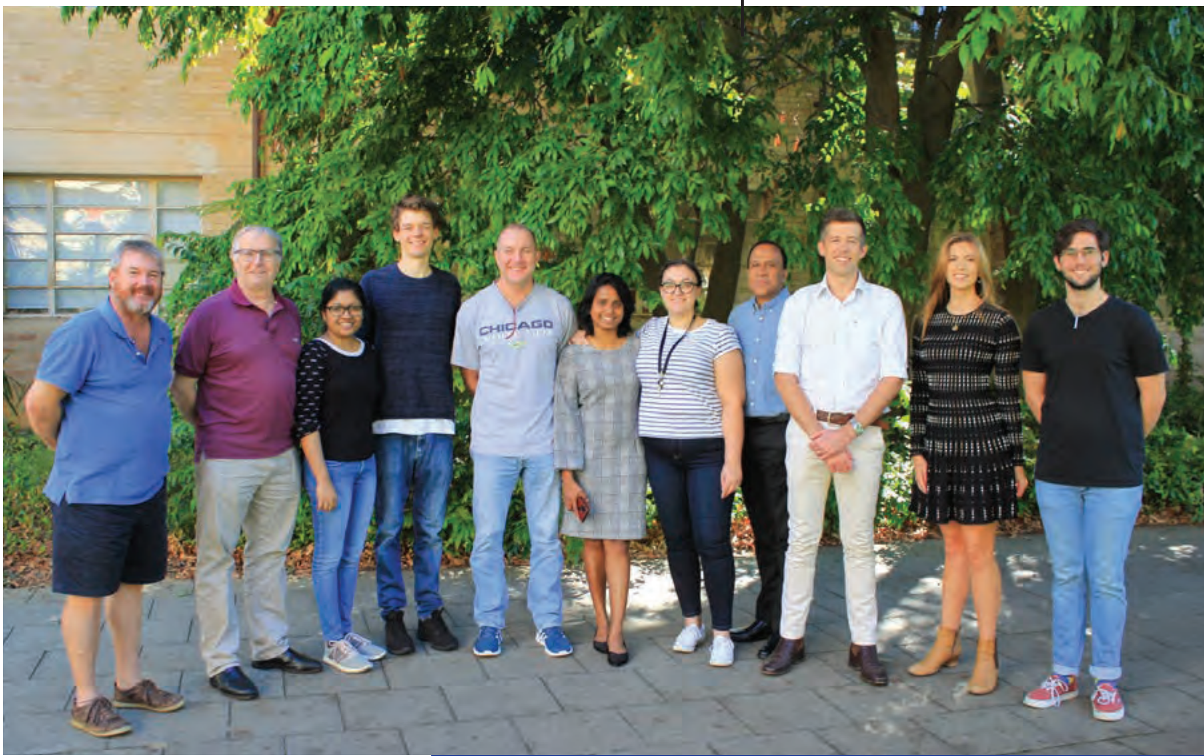
Ms Foley expanded on the R&D aspects of the business, including identifying and planning for future needs, conducting in-house trials, keeping up-to-date with the latest research, and adding to their intellectual property with technical manuals

The final speakers of the day were fourth generation broadacre farming couple Amanda and Bob Nixon from Kalannie.

Nuffield Scholar Mr Nixon outlined some innovative policies and projects on the farm, including their plan to plant 250,000 native trees to generate carbon credits and reverse the effects of salinity.

Mrs Nixon then gave an intimate insight into the family farm history and ways they were planning for the next generation.

Professor de Graaf with UWA animal science research staff and students.



Alan Sevier Memorial Lecture

UWA Adjunct Associate Professor Bruce Mackintosh, Professor de Graaf and Hackett Professor Kadambot Siddique.

The University of Sydney Associate Professor Simon de Graaf delivered bold predictions for the future of sheep artificial breeding at the IOA Alan Sevier Memorial Lecture at Bayliss Lecture Theatre.

The April 2021 lecture was held in honour of Alan Sevier – a WA farmer, inventor and amateur scientist who bequeathed his research and writings on cattle reproduction and pheromone experiments to UWA before he passed away in 2013.

Prior to the lecture, Professor de Graaf met with UWA students for a special Q&A morning tea. Professor de Graaf said new data capture system could help breeders eliminate or dramatically reduce unsuccessful AI cases.

“We would be able to look at things including the time of the AI, the dose of hormones and analgesia used, what the tone of the uterus looks like, the internal fat score and even the weather,” he said.

“You combine all of that information … and then by using the same device at pregnancy scanning, that information can be married up with the fertility data we have.”

Professor de Graaf said he hoped the device would even be able to identify if the weather impacted fertility.

“Imagine if you received a warning that said: ‘If you go ahead with your artificial insemination program now, based on the forecast, you will have 20 per cent lower conception rates’,” he said.

A group of Open Day attendees visiting a research demonstration site at Upper Cow Dam.

UWA Farm Ridgefield Open Day

Pastures and Fodder for Sustainability

UWA Farm Ridgefield was a hive of activity during its 2021 Open Day showcasing innovative research and development.

About 130 community members and leaders, farmers, researchers, students and industry representatives flocked to West Pingelly to learn first-hand about four UWA research projects underway at the farm.

Noongar Elder Garry Bennell presented the Welcome to Country, followed by an introductory speech from IOA Director Hackett Professor Kadambot Siddique.

In her opening address, Shire of Pingelly Deputy President Jackie McBurney celebrated the long-standing and productive working relationship between UWA and Pingelly community.

After a fundraiser lunch catered by the Pingelly Tourism Group, attendees boarded coaches to visit the Land Restoration Demonstration Site.

UWA Emerita Professor Lynette Abbott established the site to show how upscaling novel soil restoration practices can re-establish productivity on degraded areas of farmland.

Next on the itinerary was the 'Enrich' Forage Systems project led by Institute's Associate Director Professor Phillip Vercoe.

Against the backdrop of sheep grazing among native shrubs, Professor Vercoe explained that selecting perennial plant species with high nutritive value and low methanogenic potential had shown to improve year-round productivity and reduce the environmental footprint.

Dr Kevin Foster captured the crowd's attention with his collaborative research into oestrogenic subclover – detailing how to identify different varieties on-farm, their livestock impact, and remediation.

"We have been conducting pasture surveys across southern Australia to identify how widespread some of the older subclover varieties known to contain oestrogenic compounds are in these grazing areas," Dr Foster said.

The final stop was The Avon River Critical Zone Observatory, one of five core sites that make up the new OZCZO-network across Australia.

Dr Matthias Leopold explained that critical zone science was a holistic approach to study our environment "from the top of the tree canopy down to the bedrock".

The Pingelly Tourism Group had a full spread of baked goods and hot drinks waiting when everyone returned to the Old Farmhouse.

Attendee feedback was extremely positive, with retired farmer John Hicks praising IOA for its "exceptional hospitality" in hosting the Open Day.

"Congratulations to all the presenters – their feet on the ground and practical extension at the farmer level is to be commended," Mr Hicks said.

Professor Phil Vercoe presenting on 'Enrich' Forage Systems.

Visiting SAgE students in front of the IOA information stall.

Dowerin Field Days

The 2021 Dowerin GWN7 Machinery Field Days smashed previous attendance records with more than 24,800 people coming through the gates over two days.

After the 2020 event was cancelled due to COVID-19, crowds returned in droves – making this year the biggest field days in two decades.

The increased popularity was certainly felt at the IOA's information stall within the DPIRD Shed.

UWA senior research officers Daniel Kidd and Roberto Lujan Rocha, Research Associate Dr Joanne Wisdom and Communications Officer Rosanna Candler were kept very busy speaking with interested farmers, researchers, students and industry representatives.

The colourful stall featured information on IOA's Research Themes, Black Soldier Fly Project, UWA Farm Ridgefield, Australian Herbicide Resistance Initiative (AHRI) and more.

In the lead-up to the event, Mr Kidd grew canola, wheat, clover, rye grass and chickpea plants – which were displayed alongside cards expanding on current UWA research involving each crop.

On the first day, the foursome was joined by IOA Director Hackett Professor Kadambot Siddique and a busload of energetic agriculture students from the UWA School of Agriculture and Environment.

During her visit to the stall, The Honourable Minister for Regional Development, Agriculture and Food and Hydrogen Industry Alannah MacTiernan MLC was especially interested in discussing the Black Soldier Fly Project.

The collaborative research project between UWA, Future Green Solutions, Australian Pork and more aims to transform agricultural wastes into valuable commodities.

The Hon Minister Alannah MacTiernan speaking with Hackett Professor Kadambot Siddique.

GRDC Grains Research Update

UWA was strongly represented at the Grains GRDC Grains Research Update on February 22 and 23.

IOA's exhibition stall acted as a base for dozens of UWA students and researchers who participated in the annual event.

UWA Emeritus Professor Stephen Powles became the first Western Australian and fourth person ever to receive the prestigious Seed of Gold award.

The renowned herbicide resistance expert was presented with the award in recognition of his lifelong service to the grains industry.

On the first day, UWA SAgE Professor Ross Kingwell presented a market focus session on 'Wheat 2030 Opportunities', while Associate Professor Ken Flower presented his research on 'Patterns of crop water use in a long-term rotation trial'.

Agronomists Dr Mike Ashworth and Roberto Lujan-Rocha from UWA-based AHRI led a session on crop protection from weeds in the early afternoon.

IOA Associate Director Professor Wallace Cowling and Dr Sheng Chen then presented their research into 'Pre-breeding canola for heat stress tolerance – a prototype facility for large-scale screening at flowering stage'.

On the second day, UWA Master's student Bowen Zhang presented his project 'Cracking the code of group H cross-resistance in wild radish'.

UWA SAgE (now Murdoch University) Research Fellow Fran Brailsford delivered a research snapshot on 'Unlocking the potential of ironstone gravels', followed by soil microbiologist Dr Khalil Kariman on the 'Effects of a native symbiotic fungus on crop growth and nutrition under controlled environment conditions'.

Future Farm 2050 Project: 2021 Highlights

The Future Farm 2050 (FF2050) Project at UWA Farm Ridgefield aims to imagine the best-practice farm of 2050, and build and manage it now. The FF2050 project team regularly engages with farmers, researchers, metropolitan and rural communities and industry to share this vision, link industry and research, and inspire the next generation.

Farm Manager Richard McKenna introduces Professor Chakma to the resident sheep.

Outreach

National and international restrictions due to the COVID-19 pandemic impacted the usually high number of visitors to Ridgefield.

The UWA Vice Chancellor Amit Chakma visited UWA Farm Ridgefield for the first time in 2021. During the tour, IOA Director Hackett Professor Kadambot Siddique introduced Professor Chakma to Farm Manager Richard McKenna, his wife Cathy, several UWA researchers, and representatives from the Shire of Pingelly including President William Mulroney.

On 20 March, IOA held the Pingelly Astrofest in collaboration with the Shire of Pingelly and ICRAR. More than 500 people attended. A special information stall run by Cathy McKenna included children's activity books on Ridgefield, a craft activity, and the Ridgefield model with farm toys. The UWA Farm Ridgefield 2021 Open Day: Pastures and Fodder for Sustainability on 3 September attracted about 130 attendees, including the local community.

In April, the Wheatbelt NRM Field Day was held at Ridgefield with UWA staff involved with Smart Farms National Landcare Project. The Merino Lifetime Productivity Field Day was held at Ridgefield in October. The FF2050 Project belongs to the Worldwide Universities Network Global Farm Platform. It is also part of the Critical Zone Exploration Network (the Avon Catchment Critical Zone Observatory is based at Ridgefield), Terrestrial Ecosystems Research Network (flux towers are at Ridgefield and neighbouring Boyagin Reserve), and Animal Welfare Initiative.

FF2050 Project's strong online presence enabled engagement with people all around the world. A total of 2158 people were following the FF2050 page on Facebook by the end of 2021. Throughout the year, 27 media articles and two peer-reviewed research papers were published.

The Massive Open Online Course 'Discover Best Practice Farming for a Sustainable 2050' attracted a further 6500 enrolments in 2021, reaching a total of 30,156 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 FF2050 Project: livestock, cropping, sustainability and a vibrant community.

Education

Education is integral to the FF2050 Project, from high school students through to Bachelor, Masters and Doctorate level. The project provides an excellent platform for practical field experience.

Throughout the year, 21 Murdoch University students undertook student placement at Ridgefield. Associate Professor Matthias Leopold led about 100 students on practicum field trips to Ridgefield for the units Land Capability Assessment (ENVT3338) and Advanced Land Use and Management (ENVT 4401). In November, the founder of the FF2050 Project Emeritus Professor Graeme Martin ran a workshop for Year 11 students from the WA College of Agriculture, Narrogin.

Seven UWA postgraduate students used Ridgefield for their research projects, including:

- Bianca Berto: *Seed Enhancement technologies research at Ridgefield Farm*
- Wesley Moss: *The Need for Seed: Harvesting Natural Nitrogen*
- Gabrielle Beca: *Restoring degraded landscapes – The role of digging mammals on seedling recruitment*
- Ahmed Alsharmani: *Dynamics of arbuscular mycorrhizal fungi in pasture plants in response to fertilisers and soil amendments*
- Manish Sharma: *Black Soldier Fly Frass: a potential novel bio fertiliser to improve*

UWA Vice Chancellor Professor Amit Chakma (third from right) and the group on the farm tour.

Emeritus Professor Graeme Martin accepting the Agriculture Award from RSPCA WA Chair Lynne Bradshaw AM.

Virtual Village planning meeting with UWA Professor Loretta Baldassar, Dr Silvia Lozeva, Dr Catriona Stevens, Lee Steele, The Hon Helen Morton and Dr Lukasz Krzyzowski.

Representatives from UWA, Telstra, DPIRD, the Department of Regional Development and Communication and the Shire of Pingelly at a launch event for the Telstra tower.

soil fertility, microbial diversity and yield

- Mohammad Salim: *Morphological and physiological traits of soybean (Glycine max L.) under drought and low phosphorus environments*
- Hira Shaukat: *Mapping moisture in Variable-Textured Soils of Western Australian Wheatbelt by Non-invasive Methods*

Awards and achievements

In early 2021, E/Professor Graeme Martin was named a Fellow of the Australian Association of Animal Sciences. Professor Martin was presented the 2021 Marshall Medal by the President of the UK-based Society for Reproduction and Fertility during an online ceremony in January.

Emerita Professor Lynette Abbott, an expert in the field of soil science and soil biology, won the General Jeffery Soil Health Award. Landcare Australia filmed a video at Ridgefield to celebrate the award, with particular focus on her Land Restoration Demonstration Site research project.

The Telstra communications tower at Ridgefield was completed mid-year. It is one of more than 1200 new mobile base stations benefiting from expanded coverage, funded under the Federal Government's Mobile Black Spot Program.

The FF2050 Project is part of the Merino Lifetime Productivity Project (Ridgefield is one of five national sire evaluation sites), The Animal Welfare Collaborative, Australian Association of Animal Science and Pingelly Community Resource Centre.

RSPCA WA recognised the Non-Mulesing Producer Demonstration Site Project at Ridgefield for its "positive influence on animal welfare" with the 2021 Agriculture Award. The MLA-funded joint project between UWA and Georgia Reid and Ed Riggall at AgPro Management demonstrates the impact of shifting to non-mules for both producers and the wider industry. Ridgefield one of six non-mulesing sites where performance is measured – including weaner weight, wool value, animal price and husbandry costs.

In late 2021, the Federal Government Senior's Connected Program awarded the UWA Social Care and Ageing (SAGE) Living Lab and collaborators, including the Pingelly Somerset Alliance, a $377,750 grant to jointly establish a Virtual Village across Wandering, Wickepin, Cuballing, and Pingelly.

Future of the FF2050

IOA held a workshop in October 2021 to assist with developing a new Strategic Plan 2022-2027 for the FF2050 Project based at Ridgefield. The workshop was led by external consultant Dr Andy Paterson and attended by key stakeholders including UWA E/Professor Martin, Pro Vice-Chancellor (Research) Professor Andrew Page, Pingelly farmer Tim Watts, Institute Advisory Board member Bruce Mullan, Shire of Pingelly CEO Andrew Dover, and four of IOA's Research Theme leaders.

The aim of the workshop was to reflect on what the FF2050 Project has achieved since its inception in 2009 and consider what improvements could be made into the future.

Media statements

IOA communicated its research outcomes to the public through the media by distributing 32 media statements in agriculture and related areas in 2021. A commendable amount of media coverage was generated in local, rural, national and international print, broadcast and online media.

Date	Title
12 January	Australia New Zealand agri-food industries highly resilient during COVID-19
27 January	UWA Hackett Professor named WA Indian of the Year 2021
16 February	UWA research finds neglected and underutilised crops could help end hunger
16 February	Breakthrough research finds keys to a major boost for hybrid wheat breeding
17 February	UWA co-developed weed chipper wins best paper award
24 February	The UWA Institute of Agriculture releases new Strategic Plan
8 March	Hundreds set to scope out Pingelly Astrofest 2021
30 March	Pingelly Astrofest an astronomical success
15 April	UWA researchers discover the cause of devastating crop disease
16 April	How weeds fight back just like cancer cells
21 April	Researchers urge adoption of biotechnology for food security
1 June	New genes to improve chickpea phosphorous levels to improve crop growth
30 June	Sheep expert wins international medal
13 July	Handpicking genes for disease-resistant crops
13 July	The UWA Institute of Agriculture releases 2020 Annual Research Report
22 July	Leading soil scientist returns to UWA research roots
9 August	Soil expert scoops inaugural national award
11 August	Two UWA projects win national research funding
16 August	UWA Farm Open Day to showcase innovative research
24 August	Virtual fencing focus for BeefLinks Field Day
14 September	Growing more food with a smaller carbon footprint
15 September	Three UWA researchers recipients of Young Tall Poppy Science Awards
29 September	Fast-forward breeding for a food-secure world
22 October	Increasing virus epidemics threaten Australia's cereal and oilseed crops
26 October	New Centre for Agricultural Economics and Development to launch at UWA
2 November	Accelerated breeding for healthy African beans
11 November	Genetic variation map to enhance future chickpea breeding
11 November	Ten top researchers from UWA named the country's best
16 November	Strategies to reduce rising temperatures caused by deforestation
17 November	The UWA Institute of Agriculture celebrates highly cited researchers
30 November	Herbicide research provides sustainable farming solutions
10 December	UWA researchers dig deep to uncover soil fungi

Awards and industry recognition

Name	Award
H/Prof Kadambot Siddique	Western Australian Indian of the Year 2021
E/Prof Stephen Powles	Seed of Gold Award – 2021 GRDC Grains Research Update
E/Prof Graeme Martin	Fellow of the Australian Association of Animal Sciences 2021 Marshall Medal – Society for Reproduction and Fertility UK
Dr Andrew Guzzomi and co-authors	Most Outstanding Paper Award for publications in the Weed Technology journal
Adj/Prof Neil Turner	Medal of the Order of Australia – Queen's Birthday Honours
Dr Dawson Bradford	Medal in the general division of the Order of Australia – Queen's Birthday Honours
E/Prof Lynette Abbott	General Jeffery Soil Health Award – Office of the National Soils Advocate
H/Prof Kadambot Siddique	Certificate of Appointment to Seventh Editorial Committee of Bulletin Soil and Water Conservation – Chinese Academy of Science
H/Prof Kadambot Siddique	Certificate of Achievement for contribution to Agriculture Research and Education in India and Australia – Indian Consul General Perth
Dr Joanna Melonek	WA Young Tall Poppy Science Award
Dr Joanna Melonek	2021 Peter Goldacre Award
UWA Farm Ridgefield	RSPCA WA Agriculture Award
H/Prof Kadambot Siddique	The Australian's 2021 Research Magazine 'Top Researcher'
Assoc/Prof Ram Pandit	The Australian's 2021 Research Magazine 'Top Researcher'
H/Prof Kadambot Siddique	2021 Clarivate Highly Cited Researcher (Agricultural Sciences and Plant & Animal Science)
E/Prof Hans Lambers	2021 Clarivate Highly Cited Researcher (Agricultural Sciences and Plant & Animal Science)
Prof Nanthi Bolan	2021 Clarivate Highly Cited Researcher (Environment & Ecology)
Prof David Edwards	2021 Clarivate Highly Cited Researcher (Cross-Field)
Adj/Prof Muhammad Farooq	2021 Clarivate Highly Cited Researcher (Agricultural Sciences)
Manish Sharma	AW Howard Memorial Trust Tim Healey Scholarship
Julian van der Zanden	AW Howard Memorial Trust Postgraduate Research Fellowship
Ruby Wiese	AW Howard Memorial Trust Honours Scholarship
Miranda Slaven	AW Howard Memorial Trust Masters Scholarship
E/Prof Graeme Martin	Fellow and Life Member of the Society for Reproductive Biology

Memoranda of Understanding

Name	Date
UWA and the International Center for Agricultural Research in the Dry Areas	Renewed January 2021
UWA and the Institute of Field and Vegetable Crops – National Institute of the Republic of Serbia	April 2021
UWA and Jawaharlal Nehru University, India	Renewed June 2021

New postgraduate research students

Name	Topic	School	Supervisor/s	Funding Body
Manish Sharma	Investigating the effectiveness of Struvite (a slow-release phosphorous fertilizer, obtained from dairy wastewater) on phosphorous uptake and drought stress in legume and cereal crops	SAgE	Dr Sasha Jenkins H/Prof Kadambot Siddique Dr Jiayin Pang Prof Megan Ryan	AW Howard Memorial Tim Healey Scholarship, RTP, Research Priorities Fund University Postgraduate Award
Felipe Castro Urrea	The value of multivariate and genomic analysis to accelerate selection of low-heritability traits in field pea	SAgE	Prof Wallace Cowling H/Prof Kadambot Siddique Dr Li Li (UNE)	Charles & Annie Neumann Fellowship – PhD Scholarship in Agriculture
Hend A Mohamed	The effect of car tyres biochar, chicken manure biochar and the compost amendments on microorganisms and fertility	SAgE	Dr Zakaria Solaiman Prof Zed Rengel	Research Priorities Fund University Postgraduate Award, RTP
Hoang Vuong Dang	Integrated phytoplankton modelling for algal bloom risk prediction: linking taxonomic data and hydrodynamic-biogeochemical modelling	SAgE	Assoc/Prof Matt Hipsey Dr Stephanie Kermode Prof Carolyn Oldham	Scholarship For International Research fees, University Postgraduate Award, Ad Hoc Top-Up Scholarship
Yunxiao Zhang	Genetic dissection of a genomic region located on wheat chromosome arm 7AL harbouring yield-controlling genes	SAgE	Dr Hui Liu Prof Guijun Yan	CSC-UWA Joint Scholarship
George Mercer	Engineering an organic soil amendment to build soil carbon and generate value from urban waste streams	SAgE	Dr Bede Mickan Dr Dierdre Gleeson Prof Megan Ryan	ARC Training Centre for Transformation of Australia's Biosolids Resource, University Postgraduate Award, RTP
Sneha Priya Pappula Reddy	The effects of terminal drought in reproductive processes in Chickpea genotypes	SAgE	H/Prof Kadambot Siddique Prof Harvey Millar Dr Jiayin Pang Dr Madan Pal Dr Bhardwaj Chellapilla	Scholarship for International Research Fees, University Postgraduate Award
Sarah Babington	Validating novel biomarkers for sheep welfare	SAgE	Assoc/Prof Dominique Blache Prof Shane Maloney Dr Alan Tilbrook	RTP, University Postgraduate Award, MLA grant with University of Queensland
Nathaniel Scott Anderson	The effects of ecosystem moisture on fire regimes in the Tingle mosaic	SAgE	Assoc/Prof Nik Callow Dr Ryan Tangney Dr Joe Fontaine Dr Ben Miller Dr Alison Miller	RTP, Destination Australia Scholarship
Rex Cao	Improving herbicide efficacy on Australian farms through strategic mixes and use patterns	SAgE	Dr Roberto Busi Dr Danica Goggin Mark Slatter	RTP, supervisors, UWA Graduate Research School
Agyeya Pratap	Unraveling heat stress tolerance in bread wheat (*Triticum aestivum* L.) by investigating changes in leaf and spike proteomes	SAgE	H/Prof Kadambot Siddique Dr Nicolas Taylor Dr Madan Pal Dr Viswanathan Chinnusamy	University Postgraduate Award Scholarship for International Research Fees

New research grants

Title	Funding Period	Funding Body	Investigator/s
Determining the incidence of herbicide resistance in Australian grain cropping	2020-2023	GRDC	Dr Mechelle Owens
BeefLinks: defining the potential and application of (native) Australian plants for a carbon neutral northern beef value chain in Western Australia	2020-2023	MLA	Prof Phil Vercoe, Dr Zoey Durmic , Assoc/Prof Dominique Blache
The life and death of plant genes	2021-2023	ARC Linkage	Dr Philipp Bayer
Early stress experiences and stress resilience and emotionality in pigs	2020-2022	ARC Linkage	Assoc/Prof Dominique Blache
Developing strategies to mitigate and manage resistance to key herbicides	2020-2025	GRDC	WeedSmart
Rethinking and revitalising herbicides to counter resistance	2021-2024	ARC Linkage	Prof Joshua Mylne, Assoc/Prof Keith Stubbs, Dr Philippe Herve, Dr Bruce Lee
Unravelling the secrets of the rhizosphere of crops	2021-2025	ARC Future Fellowships	Dr Yinglong Chen
Protecting Ethiopian lentil crops	2021-2026	ACIAR	Prof Martin Barbetti, Dr Mingpei You, Adj/Prof Roger Jones
A proof of concept for technology enabled intensive marron farming	2021-2023	AgriFutures Australia	Dr Matthew Fraser, Prof Martin Barbetti, Prof Phillip Vercoe, Dr Andrew Guzzomi, Dr Leah Beesley, J Middleton, Dr Craig Lawrence
Developing commercial practices for Asparagopsis seaweed cultivation at scale: an opportunity for rapid industry growth and optimising social and environmental outcomes	2021-2023	CRC Program	Dr John Statton, Prof Gary Kendrick, Prof Phillip Vercoe
Developing the story of WA honey: Focus on Japan	2021-2022	CRC for Honey Bee Products	Dr Daniel Schepis, Dr Liudmila Tarabashkina, Prof Sharon Purchase
Investigating heat stress in ewes – reproductive performance	2021-2025	MLA	Prof Shane Maloney, Dr Kelsey Pool, Assoc/Prof Dominique Blache, Prof Diana Walker, Dr Shannon Algar
How can we engage rural youth of Timor-Leste in farming	2021-2022	ACIAR	Prof William Erskine, Rob Williams
Impact of COVID-19 on vegetable producers: The case of cauliflower and broccoli farmers in the municipality of Aileu, Timor-Leste	2021-2022	ACIAR	Assoc/Prof Fay Rola-Rubzen, Paulo Correia
Laying the foundations for the Australian Critical Zone Observatories	2021-2023	AuScope Ltd	Assoc/Prof Matthias Leopold, Assoc/Prof Sally Thompson, Prof Jason Beringer
Pastoral partners accelerating the transition	2021-2024	Gascoyne Catchment Group Inc.	Prof Phillip Vercoe
Assessing adoption and diffusion of agricultural innovations in Bangladesh	2021-2023	Krishi Gobeshona Foundation	Prof Nazrul Islam, H/Prof Kadambot Siddique, Dr Amin Mugera, Bangladesh Agricultural University
Design, establishment and benefits of edible shelter to improve lamb survival and whole-farm profitability	2021-2025	MLA	Assoc/Prof Dominique Blache, Prof Shane Maloney, Dr Diana Walker, Dr Amin Mugera
Operating funds for a UWA PhD research project to accelerate genetic gain in field peas based on genomic and optimal contributions selection	2021-2024	Norddeutsche Pflanzenzucht Hans-Georg Lembke KG	Prof Wallace Cowling, Felipe Castro Urrea
Insecticide resistance in the green peach aphid: National surveillance, preparedness and implications for virus management	2021-2024	CSIRO	Assoc/Prof Parwinder Kaur

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Theme Leaders

The Theme Leaders co-ordinate research, development and related activities in their respective areas. The Theme Leaders Committee is chaired by Professor Phillip Vercoe and Professor Wallace Cowling.

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The IAB provides IOA with industry interaction, advice and feedback. IAB members represent a cross-section of agricultural industries and natural resource-management areas.

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2021 Publications

In 2021, researchers affiliated with IOA published more than 420 peer-reviewed journal articles and book chapters.

Peer Reviewed Journals

1. Abbaszadeh-Dahaji P, Atajan FA, Omidvari M, Tahan V and Kariman K (2021). Mitigation of Copper Stress in Maize (*Zea mays*) and Sunflower (*Helianthus annuus*) Plants by Copper-resistant Pseudomonas Strains. *Current Microbiology* **78**(4): 1335-1343 doi: 10.1007/s00284-021-02408-w
2. Ahanger MA, Siddique KHM and Ahmad P (2021). Understanding drought tolerance in plants. *Physiologia Plantarum* **172**(2): 286-288 doi: 10.1111/ppl.13442
3. Ahmed WA, Xia Y, Li R, Zhang H, Siddique KHM and Guo P (2021). Identification and Analysis of Small Interfering RNAs Associated with Heat Stress in Flowering Chinese Cabbage Using High-Throughput Sequencing. *Frontiers in Genetics* **12** doi: 10.3389/fgene.2021.746816
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12. Ayre JM, Mickan BS, Jenkins SN and Moheimani NR (2021). Batch cultivation of microalgae in anaerobic digestate exhibits functional changes in bacterial communities impacting nitrogen removal and wastewater treatment. *Algal Research* **57** doi: 10.1016/j.algal.2021.102338
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25. Beckie HJ (2021). Herbicide resistance: the increasingly important role of the crop protection industry. *Pest Management Science* **77**(4):1557-1558 doi: 10.1002/ps.6244
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45. Carcamo-Fincheira P, Reyes-Diaz M, Omena-Garcia RP, Vargas JR, Alvear M, Florez-Sarasa I, Rosado-Souza L, Rengel Z, Fernie AR, Nunes-Nesi A and Inostroza-Blancheteau C (2021). Metabolomic analyses of highbush blueberry (Vaccinium corymbosum L.) cultivars revealed mechanisms of resistance to aluminum toxicity. *Environmental And Experimental Botany* **183** doi: 10.1016/j.envexpbot.2020.104338

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Acronyms

ACIAR	Australian Centre for International Agricultural Research
ACMEI	Australian Co-operative and Mutual Enterprise Index
AGT	Australian Grain Technologies
AHRI	Australian Herbicide Resistance Initiative
AIA	Ag Institute of Australia
AI-Com	Agricultural innovations for communities
AIM	Australian Institute of Management
ALBA	Annual Legume Breeding Australia
AMF	Arbuscular mycorrhizal fungi
ARC	Australian Research Council
ARF	Agrarian Research Foundation
aSSD	Accelerated Single Seed Descent
AWI	Australian Wool Innovation
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agriculture Research Institute
BASF	Badische Anilin und Soda Fabrik
BAU	Bangladesh Agricultural University
BCCM	Business Council of Co-operatives and Mutuals
CA	Conservation Agriculture
CAAS	Chinese Academy of Agricultural Sciences
CAS	Chinese Academy of Sciences
CBH	Co-operative Bulk Handling (company)
CeRDI	Centre for eResearch and Digital Innovation
CERU	Co-operative Enterprise Research Unit
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
COGGO	The Council of Grain Growers Organisations Limited
CRC	Cooperative Research Centre
CRC-P	Cooperative Research Centre Projects
CSAP	Climate-Smart Agricultural Practices
CSC	Chinese Scholarship Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEDJTR	Department of Economic Development, Jobs, Transport and Resources
DEFRA	UK Department of Environment, Food and Rural Affairs
DNA	Deoxyribonucleic Acid
DPIRD	Department of Primary Industries and Regional Development, Western Australia
DWER	Department of Water and Environmental Regulation
EIAR	Ethiopian Institute of Agricultural Research, Adama, Ethiopia
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
FEC	Faecal Egg Count
FF2050	UWA Future Farm 2050 Project, UWA Farm Ridgefield
FFLI	Food, Fibre and Land International
FISPP	Fellow of the Indian Society for Plant Physiology
FNAAS	Foreign Fellow of the Indian National Academy of Agricultural Sciences
FTSE	Fellow of the Australian Academy of Technological Sciences and Engineering
GBS	Genotyping by sequencing
GIL	Global Innovation Linkages
GIWA	Grains Industry Association of WA
GPS	Global Positioning System
GRDC	Grains Research and Development Corporation
IAB	Industry Advisory Board
ICA	International Co-operative Alliance
ICRAR	International Centre for Radio Astronomy Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IOA	The UWA Institute of Agriculture
ISABU	Institut des Sciences Agronomiques du Burundi
IWA	International Water Association
IWC	International Water Centre, Griffith University
IWYP	International Wheat Yield Partnership
KARLO	Kenya Agricultural and Livestock Research Organization
LED	Light emitting diode
LiDAR	Light Detection and Ranging
MAF	Ministry of Agriculture and Fisheries, East Timor
MAS	Marker-assisted Selection
MDC	MLA Donor Company
MLA	Meat and Livestock Australia
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
NESP	National Environmental Science Programme
NILs	Near isogenic lines
NPZ	Norddeutsche Pflanzenzucht
NSU	North South University
NSW	New South Wales
NSW DPI	New South Wales Department of Primary Industries
OCS	Optimal Contribution Selection
P	Phosphorus
PCA	Principal Component Analysis
PCR	Polymerase chain reaction
PVC	Polyvinyl chloride
QLD	Queensland
qPCR	Quantitative Polymerase Chain Reaction
QTL	Quantitative trait locus
RADB	Rwanda Agriculture and Animal Resources Development Board
R&D	Research and Development
RDE&A	Research, Development, Extension and Adoption
RDRS	Rangpur Dinajpur Rural Service
RGI	Rapid Gene Introgression
RIL	Recombinant inbred lines
RTP	Research Training Program scholarship
SAgE	School of Agriculture and Environment, UWA
SAGI	Statistics for the Australian Grains Industry
SAI	Sustainable Agricultural Intensification
SARDI	South Australian Research and Development Institute
SBS	School of Biological Sciences, UWA
SDG	United Nations Sustainable Development Goal
SIRF	Scholarship for International and Research Fees
SNPs	Single Nucleotide Polymorphisms
SRFSI	Sustainable and Resilient Farming Systems Intensification
TARI	Tanzanian Agricultural Research Institute
UAF	University of Agriculture, Faisalabad, Pakistan
UAV	Unmanned aerial vehicle
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
WA	Western Australia

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