THE UNIVERSITY OF WESTERN AUSTRALIA | Institute of Agriculture

Annual Research Report 2020

Sustaining productive agriculture for a growing world

Vision

To provide research-based solutions to food and nutritional security, environmental sustainability and agribusiness.

Mission

To enhance The University of Western Australia's (UWA) contribution to the advancement of agriculture and the management of natural resources in selected international, national and regional settings.

For Western Australia (WA), The UWA Institute of Agriculture works with the agricultural and natural resource management sectors to create knowledge and improve workforce skills, such that those committed to agriculture may advance their individual aspirations, contribute to local and regional prosperity and exercise responsible stewardship of the environment.

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, development, extension and adoption (RDE&A).

Communication

Strengthening communication links with regional industry, farmer groups and the broader regional and scientific communities.

Connecting

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

Resourcing

Increasing the pool of resources available for investment in critical RDE&A in WA and in relevant national and international issues.

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The UWA Institute of Agriculture Annual Research Report 2020

Font cover image: The COVID-19 pandemic amplified concerns surrounding food security and the resilience of agricultural systems in 2020. Photo: Valeria Aksakova

Director’s overview

On behalf of The University of Western Australia (UWA), I am pleased to present the 2020 Annual Research Report for The UWA Institute of Agriculture (IOA).

In a year marked by the significant challenges of natural disasters and the COVID-19 pandemic, I could not be more proud of IOA. Never has our vision to provide research-based solutions to food and nutritional security, environmental sustainability and agribusiness been more pertinent.

IOA’s hard-working researchers and their collaborators contributed more than 330 journal articles, books and book chapters in 2020 – well exceeding our output the previous year. We also celebrated numerous academics named on the annual Highly Cited Researchers list for 2020. These achievements are a strong reflection of our status as number one in Australia and 17th in the world for Agricultural Sciences in the 2020 Academic Ranking of World Universities.

Our collaborative and multidisciplinary research and development activities continued across the six Research Themes. In December, we bid a thankful farewell to long-standing Research Theme Leaders Professor William Erskine and Emeritus Professor Graeme Martin, and welcomed Dr Dominique Blache and Professor Shane Maloney to lead Sustainable Grazing Systems.

Communication related to UWA’s agricultural research, development and training activities gained momentum throughout 2020. To enhance public engagement with IOA’s activities, we launched a new website and added LinkedIn and YouTube accounts to our social media presence. Twenty-four media statements were distributed, generating positive coverage in the regional and international media.

This year, we continued to strengthen our engagement with industry, farmer groups, collaborators, funding bodies, and alumni. It was heartening to welcome robust socially-distanced audiences to our Postgraduate Showcase, Industry Forum and Hector and Andrew Stewart Memorial Lecture in the second half of the year. An impressive number of research and educational opportunities, presentations, workshops and field visits involving UWA Farm Ridgefield and the Future Farm 2050 Project also took place in 2020. Due to travel and crowd restrictions, IOA embraced the ‘new normal’ by participating in online meetings and webinar events. This surge in online activities was demonstrated by more than 15 thousand enrolments in the Massive Open Online Course *Discover Best-Practice Farming for a Sustainable 2050.*

I wish to acknowledge IOA staff, researchers, associates, students, Management Board members, Industry Advisory Board members and Research Theme Leaders, as well as our national and international collaborators and funding bodies for their continued support and assistance throughout 2020.

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

The UWA Institute of Agriculture
The University of Western Australia

The Industry Advisory Board's (IAB) strong partnership with IOA was further fortified in 2020. The IAB is IOA's first port-of-call for guidance and support on agricultural industry trends, needs and issues. By working together in close partnership, we are advancing the agricultural and natural resource management sectors in WA and beyond.

In August, members of the IAB joined key leaders from UWA and the agriculture industry at a workshop to finalise the *Strategic Plan 2021-2025*. I am confident that this document will guide IOA in leading WA towards a sustainable and profitable agri-food sector for many years to come. The Board met with the new Vice-Chancellor Professor Amit Chakma during the September meeting and discussed strategies to strengthen IOA activities.

Assisting IOA with its 14th annual Industry Forum was a significant achievement in 2020. For many members of the agricultural and research community, this event was the first opportunity in months to come together in person due to COVID-19 restrictions. The topic 'Climate change and agriculture: Challenges and solutions for Australian farmers' clearly struck a chord – inspiring lively discussion and numerous newspaper articles.

UWA Farm Ridgefield activities are a priority interest of the IAB and updates are regularly provided, which allows feedback to the management committee.

I look forward to continuing to work with IOA to achieve our common goals. Thank you to members of the IAB, all contributors to IOA, and Director Hackett Professor Kadambot Siddique and his team.

Dr Terry Enright
Chair of the IOA Industry Advisory Board

UWA welcomed its 19th Vice-Chancellor Professor Amit Chakma in July 2020. Having proven his aptitude for building research capability and partnerships across academic, government and industry during his decade at The University of Western Ontario, Professor Chakma strongly supports the important role of institutes at UWA.

In a significant achievement for the university, UWA moved up several places in the 2020 global rankings, including the ARWU (85) and Quacquarelli Symonds (86). This was made possible through the university's outstanding research by our dedicated staff and research students, and strong support from industry and partners. Agricultural research, teaching and postgraduate student research training are important activities at UWA and IOA plays a significant role in these endeavours.

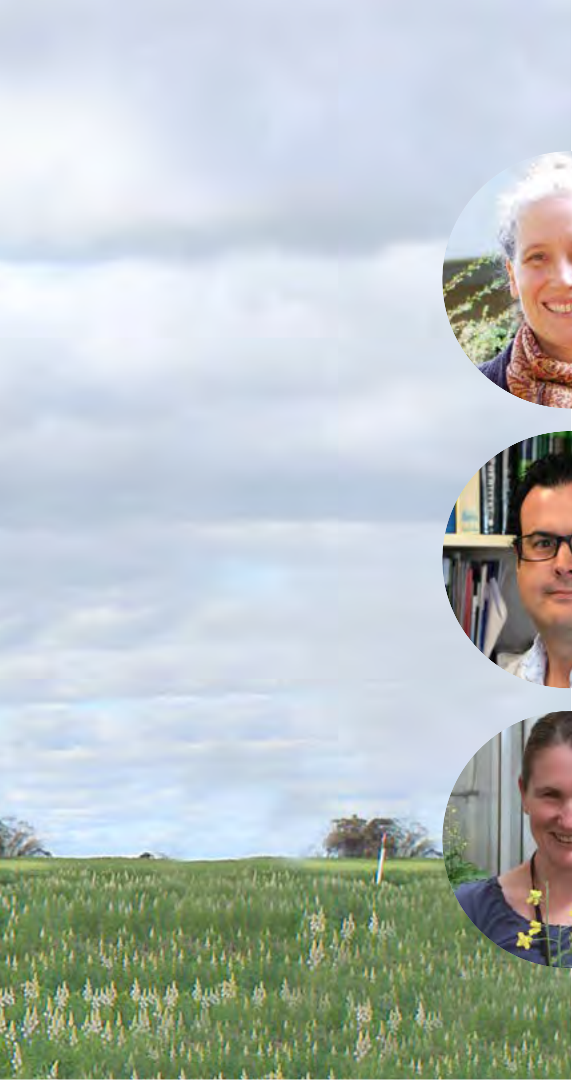
Having attended the 2020 workshop to finalise the IOA *Strategic Plan 2021-2025*, I was especially pleased to see the ways in which this future-focused document was consistent with and supported the *UWA 2030* vision and *UWA Strategic Plan 2020-2025*. It is clear that IOA's communication and engagement activities – including its regular media statements, public lectures and events and translational activities involving the UWA Farm Ridgefield – have stimulated discussion and together with research success led to positive outcomes for the WA agricultural sector. The strong international engagement by IOA continues to steward important international research collaborations.

I am very grateful to all who have supported IOA in its considerable achievements for 2020.

Professor Tim Colmer
Deputy Vice-Chancellor (Research)

The University of Western Australia

Field day at COGGO lupin trial. From left, Professor Wallace Cowling, Dr Candy Taylor, Julian van der Zanden, and Dr Matthew Aubert.

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Crops, Roots and Rhizosphere

Theme Leaders

Professor Megan Ryan
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The Crops, Roots and Rhizosphere 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.

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

UWA researchers are involved in projects focussed on topical areas, including 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. However, 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.

A cosmopolitan fungal pathogen of dicots adopts an endophytic lifestyle on cereal crops and protects them from major fungal diseases

Project team: Professor Dahong Jiang[1] (project leader; daohongjiang@mail.hzau.edu.cn), Professor Martin Barbetti[2], Professor Brett Tyler[3], Dr Puyun Yang[4], Dr Binnian Tian[1], Dr Jiatao Xie[1], Professor Yanping Fu[1], Dr Jiasen Cheng[1], Dr Bo Li[1], Dr Tao Chen[1], Dr Ying Zhao[1], Dr Zhixiao Gao[1]

Collaborating organisations: [1]Huazhong Agricultural University; [2]UWA; [3]Agriculture and Consumer Protection Department, Oregon State University; [4]Food and Agriculture Organisation of the United Nations

Fungal pathogens are seriously threatening food security and natural ecosystems; efficient and environmentally friendly control methods are essential to help safeguard such resources for increasing human populations on a global scale.

This study found that *Sclerotinia sclerotiorum*, a widespread pathogen of dicotyledons, can grow endophytically in wheat, rice, barley, maize, and oat – providing protection against Fusarium head blight, stripe rust, and rice blast. Protection is also provided by disabled *S. sclerotiorum* strains harbouring a hypovirulence virus.

The results showed that wheat infected with Sclerotinia showed up to 60 per cent reduction in Fusarium head blight and up to 65 per cent reduction in stripe rust. In terms of plant growth, the crops saw a yield increase of between 15 and 18 per cent.

This research is supported by the National Natural Science Foundation of China, National Key R&D Program, and China Agriculture Research System.

1: Professor Daohong Jiang with Dr Ming Pei You and Professor Martin Barbetti from UWA inspecting field trials in China.

2: Representative image of DT-8-treated and nontreated wheat plant at the anthesis stage in field.

Physoderma, not *Olpidium*, is the true cause of faba bean gall disease of *Vicia faba* in Ethiopia

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], Dr Joop van Leur[4]

Collaborating organisations: [1]UWA; [2]Debre Birhan Agricultural Research Centre; [3]ICARDA; [4]NSW DPIRD

This research project identified that the pathogen *Physoderma viciae* is the true cause of faba bean gall disease. Faba bean gall disease causes significant destruction of bean crops in Ethiopia and China. When the disease arrived in Ethiopia in 2012, surveys of a region showed that 50 to 100 per cent of crops quickly become infected, followed by losses up to 100 per cent. Faba bean is of critical importance for food security in Ethiopia, and faba bean gall disease is especially devastating for this East African community. It is also known to attack field peas and clover growing nearby, and poses a serious international biosecurity risk for its potential to be accidentally introduced into other countries, including Australia.

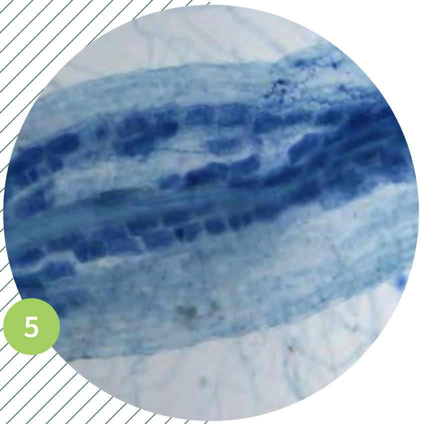
For decades, researchers around the world had tried and failed to identify the exact cause of this disease. Over two years, UWA researchers designed, made and tested many different primers in the lab to identify the pathogen behind faba bean gall disease.

For more than a century, the control and management of faba bean gall disease was based on the wrong pathogen, *Olpidium viciae*, which is different in terms of its biology, infection and spread strategies. The first appearance of symptoms of faba bean gall disease occurs when areas of the upper leaf surface produce masses of water-splashed zoospores - a spore capable of swimming. These are located in specialised sunken-well structures on leaves that the pathogen cleverly tricks the plant into producing for the sole benefit of the pathogen. Management strategies can now be aligned with the nature and behaviour of the pathogen.

This research is supported by ACIAR and UWA.

3: A faba bean plant infected with faba bean gall disease.

4: UWA Professor Martin Barbetti and Senior Research Fellow Joop van Leur with Dr Seid Kemal (ICARDA) second from right.



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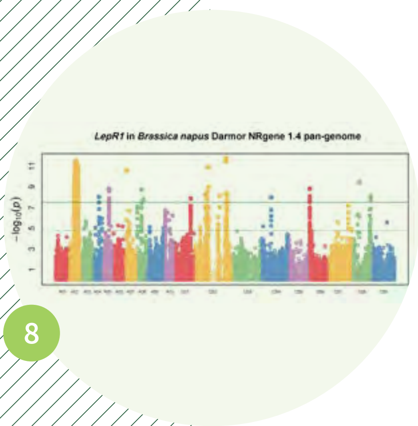

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Abundance and diversity of fine root endophytes in farming systems across Australia

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

Collaborating organisations: [1]UWA; [2]Murdoch University; [3]University of Warwick; [4]Lincoln University

Fine root endophytes (FRE) are arbuscule-forming root-colonising fungi. Historically, FRE have been incorrectly placed in the subphylum *Glomeromycotina* along with the arbuscular mycorrhizal fungi (AMF), however, previous work at UWA proved that FRE are instead placed in subphylum *Mucoromycotina*. Little is known about FRE and their role in agricultural systems.

In this project we investigated the abundance, diversity, and function of FRE in Australian agricultural and natural ecosystems. In 2020, we completed and published a study commenced by UWA PhD student Suzanne Orchard. In this study we sampled FRE and AMF in roots of subterranean clover from 58 sites across temperate southern Australia and investigated the environmental drivers of composition, richness, and root colonisation. We found that FRE and AMF showed the same responses to some (e.g. soil P, soil pH) and different responses to other (e.g. temperature) key environmental factors. FRE were present at 74 per cent of sites and AMF at 100 per cent.

In 2019, we sampled agricultural systems (e.g. truffle farm, pastures, apple orchard, cereal cropping, corn, lupins) and their nearby natural ecosystems in Queensland, WA, the Northern Territory, and Tasmania. DNA was extracted from roots and the communities of FRE and AMF characterised. In 2020, data was analysed. We found that AMF are common across Australia in natural and agricultural systems, whilst FRE have a more restricted distribution.

This is the largest study of FRE undertaken globally. We expect it will be a catalyst for more research on their role in agricultural systems.

This research is supported by the ARC.

5: Abundance and diversity of fine root endophytes.

6: Project team members sampling agricultural systems and their nearby natural ecosystems.

Exploring the genetic potential in *Brassica napus* cultivars and its relatives for Blackleg resistance genes (R genes)

Project team: Professor Jacqueline Batley[1] (project leader; jacqueline.batley@uwa.edu.au), Professor Dave Edwards[1], Dr Philipp Bayer[1], Professor Wallace Cowling[1], Dr Angela Van De Wouw[2], Anita Severn-Ellis[1], Dr Aneeta Pradhan[1], Aldrin Cantila[1], Dr Soodeh Tirnaz[1], Dr Yueqi Zhang[1], Nur Shuhadah Mohd Saad[1], William Thomas[1], Junrey Amas[1], Tingting Wu[1], Ganesh Hariharan Raj Venkadesan[1]

Collaborating organisations: [1]UWA; [2]The University of Melbourne

This project aims to:

- Explore germplasm for existing R genes in *B. napus* and novel R genes in its relatives using advanced next generation sequencing, such as whole genome resequencing (WGRS)
- Validate genomic regions containing R genes using genome wide association studies (GWAS), and
- Gain further understanding of the mechanism of blackleg R genes (existing or novel) and elucidate their relevance in canola breeding.

Of the 20 identified blackleg R genes derived from different Brassica species, only *LepR3*, *Rlm2*, and *Rlm9* are cloned. Among the genes yet to be cloned, the following genes are currently being investigated in *B. napus* and *B. juncea*.

Through GWAS *LepR1* has located on chromosome A02. Using the RGAugury pipeline we identified 25 candidate R genes in each of the reference genome and pan genome. Currently, gene-specific markers for the candidate genes are being developed and will be subject to validation in several canola lines.

LepR2 has been genetically mapped to chromosome A10, however its exact genomic position is still unknown. Taking advantage of the ancestral synteny between cabbage and canola, which share genetic material, the *LepR2* region on A10 was narrowed down substantially and a list of candidate R genes that can be used for further analysis has been generated.

Rlm1 and the cloned *LepR3* genes are both known to interact with *AvrLm1-L3*. GWAS analysis using lines without *LepR3* revealed a strong association for *Rlm1* on chromosome A07 and a list of nine candidate genes within the region were identified. Sixteen *B. napus* cultivars showing a resistant response to *AvrLm6* were identified following phenotypic screening, suggesting a new napus-derived *Rlm6* gene. Three regions on chromosome C03 were identified as potentially containing candidates for Rlm6-napus.

A phenotyping experiment that included 24 *B. juncea* lines showing resistance to AvrLm6 and 24 *B. juncea* lines showing susceptibility to AvrLm6 was carried out, followed by WGRS. Further GWAS will be conducted to identify the candidate *Rlm6* gene in *B. juncea*.

The chromosomal position of *RlmS* has yet to be determined. However, it is speculated that *RlmS* and *LepR2* may be allelic variants of the same genes. To confirm this, and to pinpoint the location of *RlmS*, a mapping population derived from an RlmS resistant and susceotible lines has been developed.

Quantitative resistance (QR) is also being explored to reinforce the protection afforded by R genes against blackleg. Genomic analysis based on previously identified quantitative trait loci revealed at least 36 consistent genomic regions conferring QR. Chromosomes A09 and C04 contain the greatest number of consistent regions and may be considered genomic 'hot-spots' for QR.

The cloning of these genes will allow researchers to develop molecular markers that can be used as diagnostic tools to determine the blackleg R gene content of canola lines. Once cloned, these genes can be more efficiently deployed to protect canola crops from yield loss caused by blackleg.

This research is supported by the ARC and GRDC.

7: Blackleg disease manifested in a. resistant and b. susceptible response to L. maculans infection and c. the selected Australian cultivars bulked for screening and whole-genome re-sequencing grown in glasshouse condition.

8: Manhattan plot showing SNPs identified from GWAS that are associated with LepR1-mediated Blackleg resistance.

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 Kazusato Ohshima[5], Dr Mohammad Hajizadeh[6], Professor Cesar Fribourg[7], Dr Jan Kreuze[8], Dr Segundo Fuentes[8], Professor Alexander Karasev[9], Kelsie Green[9], Arturo Quintero-Ferrer[9], Dr Mohamad Chikh-Ali[9], Professor Calum Wilson[10], Dr Marleen Botermans[11], Dr Monica Kehoe[12]

Collaborating organisations: [1]UWA; [2]FERA Science LTD, UK; [3]University of Newcastle, UK; [4]Australian National University, [5]Faculty of Agriculture at Saga University, Japan; [6]University of Kurdistan, Iran; [7]National Agrarian University, Peru; [8]International Potato Centre, Peru; [9]University of Idaho, USA; [10]Tasmanian Institute of Agriculture; [11]Netherlands National Plant Protection Organization Service; [12]DPIRD

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 1990s. Sequencing 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.

Historical plant virus isolates originating between the 1930s and the early 1980s were preserved by desiccation or by freeze drying. In 2014-2019, they were sequenced, mostly by FERA Science Ltd (all viruses), York, UK or the University of Idaho, Moscow, USA (potato virus Y only) to obtain complete viral genomic sequences. These historical genomes were compared with others of the same viruses that were newly sequenced or obtained from the GenBank database. The dating studies compared old with new sequences of the same virus to determine its rate of mutation and use this to date when divergences occurred.

In 2020, dating studies undertaken with members of the Potyvirideae, one of the three most damaging virus families in terms of global crop disease, provided important new information about their evolution. For example, Potyvirideae fell into 11 genera of which the genus potyvirus, the largest, includes more than 150 distinct viruses found worldwide. The first potyvirus probably originated 15,000–30,000 years ago, in a Eurasian grass host, by acquiring crucial changes to its coat protein and HC-Pro protein, which enabled it to be transmitted by migrating host-seeking aphids. All potyviruses are aphid-borne and, in nature, infect discreet sets of monocotyledonous or eudicotyledonous angiosperms.

Moreover, the potato virus A datings obtained were supported by independent historical coincidences. Its populations apparently arose in the Andes approximately 18 centuries ago, and were taken to Europe after the arrival of Europeans, radiating there after the mid-19th century potato late blight pandemic. Potato virus A's phylogroup A population diverged more recently in the Andean region, probably after new cultivars were bred locally using newly introduced *Solanum tuberosum* subsp. tuberosum as a parent. Phylogroup A, and its interphylogroup recombinants, may pose a biosecurity risk. In addition, comparisons between European potato virus Y sequences from different eras revealed major alterations in its predominant strains between the 1940s and the current era. Such knowledge over virus evolution and population changes is important when it comes to developing and revising strategies to manage virus diseases effectively under changing circumstances such as those resulting from climate change.

This research is supported by the UK DEFRA Future Proofing Plant Health Project, EUPHRESCO VirusCurate project, Japan Society for the Promotion of Science, USDA-NIFA-NRI, SDA-NIFA-SCRI, USDA-NIFA-Hatch, USDA-ARS, Idaho State Department of Agriculture, Northwest Potato Research Consortium, Idaho Potato Commission, Washington State Potato Commission, Idaho Agricultural Experiment Station, CGIAR Research Program on Roots, Tubers and Bananas.

The research is also supported by CGIAR trust fund contributors, Peruvian Programa Nacional de Innovacion Agraria, The Bill and Melinda Gates Fund, University of Kurdistan, Saga University Japan, National Agrarian University Peru, The Netherlands Plant Protection Service, Tasmanian Institute of Agriculture, DPIRD and UWA.

9: Row of potato plants killed by infection with potato virus Y (front). Other rows show healthy potato plants.

10: Specimens retrieved from a historical collection of plant virus isolates. The isolates were desiccated over silica gel in Peru in 1978, preserved in the UK inside this tin until 2014, and then sequenced.

Fine mapping and gene cloning in the post-NGS era: advances and prospects

Project team: Dr Rajeev Varshney[1,2] (project leader; r.k.varshney@cgiar.org), Dr Deepa Jaganathan[2,3], Dr Abhishek Bohra[4], Dr Mahendar Thudi[2]

Collaborating organisations: [1]UWA; [2]ICRISAT; Tamil Nadu Agricultural University; [3]ICAR-Indian Institute of Pulses Research

Improvement in traits of agronomic importance is the top breeding priority of crop improvement programs. The majority of these agronomic traits show complex quantitative inheritance. Identification of quantitative trait loci (QTL) followed by fine mapping of QTLs and cloning of candidate genes/QTL is central to trait analysis. Advances in genomic technologies revolutionized our understanding of genetics of complex traits, and genomic regions associated with traits were employed in marker-assisted breeding or cloning of QTL/genes. Next-generation sequencing (NGS) technologies have enabled genome-wide methodologies for the development of ultra-high-density genetic linkage maps in different crops, thus allowing placement of candidate loci within a few KBPs in genomes.

In this review, authors compared the marker systems used for fine mapping and QTL cloning in the pre- and post-NGS era. They then discussed how different NGS platforms in combination with advanced experimental designs have improved trait analysis and fine mapping. The authors opined that efficient genotyping/sequencing assays may circumvent the need for cumbersome procedures that were earlier used for fine mapping. A deeper understanding of the trait architectures of agricultural significance will be crucial to accelerate crop improvement.

This research is supported by the Department of Science & Technology and Tropical Legumes project funded by the Bill and Melinda Gates Foundation (BMGF) through CGIAR-Generation Challenge Program and DBT (Government of India).

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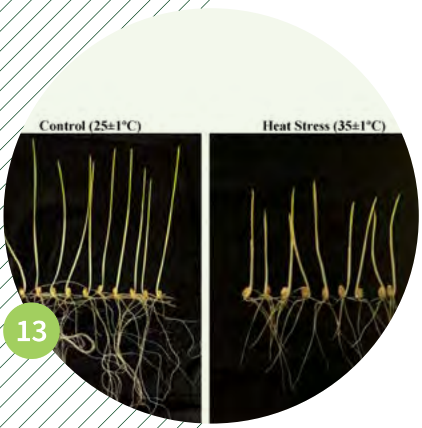
11: Comparison of marker development, map and QTL resolution during the pre- and post-NGS era. In the pre-NGS era, QTL resolution is low (10–30 cM), while in the post-NGS era the QTL resolution is high (0.5–10 cM).



Increasing wheat yield by genomic sequencing and germplasm exchange

Project team: Professor Guijun Yan[1] (project leader; guijun.yan@uwa.edu.au), Professor David Edwards[1], Professor Jacqueline Batley[1], Dr Hui Liu[1], Dr Daniel Mullan[2], Professor Aimin Zhang[3], Professor Yong Zhang[4], Professor Zhanyuan Lu[5], Professor Yong Wang[6], Dr Shancen Zhao[7]

Collaborating organisations: [1]UWA; [2]InterGrain; [3]Chinese Academy of Science; [4]Chinese Academy of Agricultural Sciences; [5]Inner Mongolia Academy of Agriculture and Animal Husbandry Sciences; [6]Gansu Academy of Agricultural Sciences, [7]Beijing Genomics Institute

This project aims to apply genome sequencing technology to investigate diverse germplasm resources in Australia and China, and to accelerate the breeding of high yielding wheat with good quality and adaptability in target environments.

The progress of this project in 2020:

- About 3000 hybrids, generated from the crosses of exchanged Australian and Chinese cultivars, are being advanced and evaluated in the glasshouses of UWA and InterGrain
- Field trials of 150 Australian and Chinese wheat lines were undertaken in different Australian locations, and
- A collection of 548 hybrid lines and cultivars with traits of interest have been tested on the newly developed 25K Wheat Breeder's SNP array chip for gene identification and validation.

This research is supported by the GIL Program, Department of Industry, Science, Energy and Resources.

12: A plot showing marker-trait associations for five agronomic traits including plant height, biomass, spike number, grain number, thousand kernel weight (TKW) and grain yield (in the order from inner circle to outer circle).

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 an important cereal crop contributing a large proportion of human calories worldwide and a major cereal for domestic consumption and export in Australia. It is a winter crop and the production is highly affected by the fluctuation in day-night temperature. Increasing temperature due to climate change has challenged wheat production, which makes breeding for heat-tolerant wheat varieties a prime need, to cope with global food security.

Breeding for a polygenic trait like heat tolerance in hexaploid wheat is a 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 by transcription factor (TF) genes, heat-responsive genes and production of metabolites (Singh et al., 2019).

Therefore, TF genes act as a switch to regulate heat tolerance mechanism in wheat. To understand the role of TF genes in wheat heat tolerance, we aim to identify key TF genes responsive to HS, characterise them and analyse their expression at seedling and reproductive stages, in wheat genotypes which are phenotypically contrasting for heat tolerance.

In 2020, we selected the AP2/ERF super-family as the target gene family for expression analysis in wheat under heat stress. A genome-wide homology search identified 630 AP2/ERF genes in wheat. These were studied for presence of conserved domains and motifs, chromosomal location, biochemical characteristics and phylogeny. Based on the presence of conserved domains, these genes were categorized into three major gene families (AP2 family with two AP2-domains, RAV family with one AP2 and one B3-domain, and ERF/DREB family with a single AP2-domain). We selected 350 representative TF genes for in-silico expression analysis using a wheat expression database under abiotic stress. Among differentially expressed TaAP2/ERF genes, 35 TF genes highly expressed under abiotic stress in roots and leaves at seedling, vegetative and reproductive stages were selected for further validation using qPCR analysis.

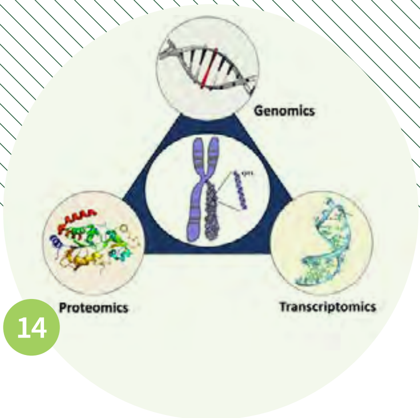
We geminated seeds of selected wheat genotypes at room temperature for 36 hours and incubated at 25±1ºC for control and 35±1ºC for heat treatment. These plants were sampled three and seven days after heat treatment and RNA extracted. Simultaneously, morphological characters such as root length, shoot length and root characters were measured.

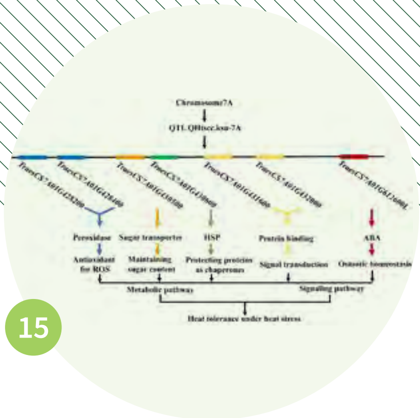
In 2021, we will conduct molecular validation of these samples using qPCR and the TF genes highly expressed under heat stress at seedling stage will be identified. The plants will be grown under glasshouse and exposed to heat stress at anthesis to understand the heat tolerance mechanism at reproductive stage.

In conclusion, genome-wide analysis and validation of TaAP2/ERF TF genes will provide a detailed 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 GIL Project.

13: Response of early-stage wheat seedlings under control and heat stress showing clear differences in seedling and root length.





Genetic studies of drought tolerance in bread wheat

Project team: Sina Nouraei[1], Professor Guijun Yan[1] (project leader; guijun.yan@uwa.edu.au), Adjunct Professor Neil Turner[1], Dr Hui Liu[1], Dr Sultan Mia[1]

Collaborating organisation: [1]UWA

Wheat (*Triticum aestivum* L.) is the most important cereal crop in Australia and a major export crop for Western Australia. However, water shortage severely limits wheat production in many parts of the world, as well as Australia where it is mostly grown in areas with a yearly precipitation of less than 650mm. To produce more food for a growing world population and to cope with increased water shortage caused by global warming, production of drought tolerant wheat is aneeded.

Despite complex multi-gene control of the quantitative drought-tolerance traits and the complexity of the polyploid wheat genome, several quantitative trait loci (QTL) with many linked markers have been detected on different chromosomes of wheat for yield and yield components under drought stress. Nevertheless, using these QTL in breeding programs requires better understanding of the genes, gene pathways and the interactions between them, and the environment. To pave the way for breeding drought tolerant wheat, we aim to identify the genes and gene pathways underpinning drought tolerance QTL, based on genomic, transcriptomic and proteomic analysis of multiple near-isogenic lines (NILs) of wheat that we developed.

In 2020, we conducted a glasshouse experiment with four NIL pairs that were different for an important QTL responsible for drought tolerance on the 4B chromosome of wheat. These four sets of NILs were developed from a cross between C306 containing a drought-tolerant QTL qDSI.4B.1 and Dharwar Dry following the heterogeneous inbreed family (HIF) analysis coupled with immature embryo culture-based fast generation technique (2016 - 2018). The plants were grown in similar conditions until anthesis when two water treatments were applied: (i) well-watered (WW) and (ii) drought stressed (DS). Seed and leaf samples were taken at seven days and 14 days post anthesis. According to the phenotypic data, including yield and yield related traits, two NIL pairs that showed the greatest differences between +NIL and –NIL in the DS treatment were selected and samples taken for further analysis.

In 2021, we will conduct genomic, transcriptomic and proteomic studies on these samples. Since the only difference between the NIL pairs is the presence or lack of one drought-related QTL, the differences in the cellular components at the DNA, RNA and protein levels should be attributable to this important QTL.

Overall, the results of the genomic, transcriptomic and proteomic analyses will provide comprehensive information about the 4BS locus and its role in drought tolerance, in addition to providing the prerequisites for future investigations by fine mapping and gene cloning.

This research is supported by UIFS, UPA and GIL Project.

14: The overall scheme of the research is to use omics tools for better understanding of the 4BS QTL responsible for drought tolerance.

15: Experiment in progress. From left (i) the researcher, (ii) well-watered treatment, (iii) seven days after water stress and (iv) 14 days after water stress.

16: A set of NIL pair (+NIL and –NIL) at seven days after water stress. Genotype with the positive allele showed more tolerance than the one with the negative allele.

Genetic studies of heat tolerance in wheat at different growth (seedling vs reproductive) stages

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

Collaborating organisation: [1]UWA

Wheat is one of the most important food crops in the world. As a cool-season crop under a changing climate it is more prone to heat stress, which severely affects crop production and grain quality. During the reproductive stage, wheat is highly susceptible to high temperatures. However, due to the convenience of screening, evaluating heat tolerance (HT) of wheat germplasm at the seedling stage is a good option. Hence, it's meaningful to study the correlation of wheat performance under heat stress at different growth stages. HT in wheat is a quantitative trait, and the genes underlying the reported quantitative trait loci (QTL) have rarely been identified or clearly annotated. Recombinant inbred lines (RIL) and near-isogenic lines (NILs) can be readily developed as suitable material for identifying candidate genes for targeted QTL, and various omics can be utilised to extend our understanding of the genetic network mechanism underlying HT in wheat.

The main aim of this project is to extend our understanding of the genetic mechanism underlying HT in wheat. The specific objectives are to:

- Explore the potential relationship between HT at seedling stage and at the reproductive stage
- Identify QTL associated with HT and develop closely linked DNA-markers for wheat HT breeding
- Identify associated candidate gene(s) within particular chromosome regions of HT QTL, and
- Screen major metabolic differences to find what metabolic component dominates the changes in response to heat stress.

The highlight of 2020 comes from the achievement of the third specific objective above, the outcomes include:

- Four NIL pairs were developed and confirmed targeting the major heat tolerance QTL on chromosome 7A, and
- Seven candidate genes were identified underlying the 7A QTL responsible for HT by genotypic and phenotypic characterisation of the NILs.

The confirmed NILs and identified candidate genes are valuable resources for future studies in fine mapping and functional analyses of the chromosome region to clone the underlying gene(s). The discussion on the relationship of the related genes extended our understanding of the genetic mechanism of HT.

This research is supported by the GIL Project and RTP Scholarship.

17: Postulated pathway based on the findings of this study showing a collaborative regulation network of multiple genes in wheat in response to heat stress. Signalling pathway and metabolic pathway involving a series of physiochemical processes and important molecules, including heat-shock proteins, antioxidants, metabolites, and hormones.

18: A wheat field in Western Australia.

Root trait genetic variations and associated genes of near-isogenic lines in bread wheat

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

Collaborating organisation: [1]UWA

Wheat (*Triticum aestivum* L.) is one of the most important global cereal crops. Identification of genetic variation and genes associated with the specific root traits in wheat provides a promising way to improve root system for better adaptation and grain yield. Ten pairs of near-isogenic lines (NILs) of wheat previously developed targeting four different quantitative trait locus (QTL) on chromosomes 4BL (QPhs.ocs-4B.1), 4BS (qDSI.4B.1), 4AS (qDT.4A.1) and 7AL (QHtscc.ksu-7A) of bread wheat were used in this project. Root morphological traits of these NILs at the tillering stage were characterised in a semi-hydroponic phenotying system and genetic variations and associated candidate genes for ten root traits were identified. NIL targeting qDSI.4B.1 QTL showed most variations between their isolines followed by NIL targeting qDT.4A.1 for the root traits. In pairs 5-7 with qDT.4A.1 QTL, pair 6 showed significant differences for six root traits.

To identify candidate genes controlling the root traits of the NIL pairs, the wheat 90K Illumina iSelect array was used. Using 108 single nucleotide polymorphism (SNP) markers, 321 genes were identified. However, only 25 genes were selected based on the role of the protein encoded by the genes for root growth, development and controlling root traits in other crops including wheat reported in earlier studies. Among all the genes, a novel gene; *TraesCS4B01G114500* that encodes Phox-associated domain, sorting nexin isoform 3 was identified in NIL pair with qDSI.4B.1. Another three outstanding root trait controlling genes were identified in qDT.4A.1: UDP-glycosyltransferase (UGT) encoding genes *TraesCS4A02G185300* and *TraesCS4A02G442700*, and leucine-rich repeat receptor like protein kinases (LRR-RLK) encoding gene *TraesCS4A02G330900*. The proteins encoded by these genes are reported as potential proteins for root trait control in other crops. No gene encoding the proteins have been reported in wheat to date.

The root-related genes identified in the study will be useful in breeding programs, following functional validation of the genes.

This research is supported by the Australian Government RTP.

19: PhD student Tanushree Halder inspecting wheat growth in the semi-hydroponic phenotyping system for characterising root traits.

Genome assembly of the fungal guava wilt disease pathogen *Nalanthamala psidii*

Project team: Anita Severn-Ellis[1], Professor Jacqueline Batley[1] (project leader; jacqueline.batley@uwa.edu.au), Dr Philipp Bayer[1], Professor Dave Edwards[1], Maritha Schoeman[2], Arthur Sippel[2]

Collaborating organisations: [1]UWA; [2]ARC Institute for Tropical and Subtropical Crops

Nalanthamala psidii is a destructive fungal pathogen and the cause of guava wilt disease (GWD). The pathogen affects guava (*Psidium guajava*) production in South Africa, as well as several South East Asian countries, resulting in severe losses in production and livelihoods. The use of resistant varieties remains the only effective strategy in the control of GWD as chemical control measures to date are ineffective in the management of GWD. Tree crop breeding is challenging and time-consuming and the emergence of additional GWD pathogen races has added another level of complexity in the development of guava varieties with durable resistance.

Capturing the benefits of next generation sequencing (NGS) and associated technologies the genome and transcriptome of *N. psidii* wilt pathogen was sequenced, assembled and annotated. The 38.57Mb genome is the first reported sequenced genome for the genus *Nalanthamala*. It furthermore contributes towards the list of sequenced fungal genomes within the *Nectriacea* family, in particular the *Rubrinectria* clade. An in-depth analysis of the *N. psidii* genome revealed a diverse array of secreted polysaccharide-degrading enzymes, proteases, lipases as well as peroxidases associated with plant cell wall degradation reflecting its necrotrophic nature. The identification of known and predicted effector repertoire along with the putative secondary metabolite clusters found has created an important resource for further studies. In addition, putative transcription factors, kinases and transporters including the important ABC and MFS transporters involved in the efflux of fungicides were identified.

Knowledge of these regulatory and transport proteins provide an opportunity to review and develop new strategies for the control. The detection of mechanisms linked to reproduction such as het and mating genes in conjunction with its repetitive landscape has provided insights into the biological complexity and to evolutionary potential of this non-model pathogenic fungus. It is envisioned that the genomic resource created will in future contribute towards the effective disease management and better-informed breeding strategies.

This research is supported by ARC Institute for Tropical and Subtropical Crops, SAGGA, SANRF, and Pawsey Supercomputing Centre.

20: A guava tree infected by Nalanthamala psidii displaying rapid sectorial decline.

Strategies for effective use of genomic information in crop breeding programs serving Africa and South Asia

Project team: Dr Kelly Robbins[1] (project leader; krr73@cornell.edu), Dr Nicholas Santantonio[1], Dr Sikiru Adeniyi Atanda[1], Dr Yoseph Beyene[2], Adjunct Professor Rajeev Varshney[3,4], Dr Michael Olsen[2], Dr Elizabeth Jones[1], Dr Manish Roorkiwal[4], Dr Manje Gowda[2], Dr Chellapilla Bharadwaj[5], Pooran Gaur[4], Xuecai Zhang[2], Dr Kate Dreher[2], Dr Claudio Ayala-Hernández[3], Dr Jose Crossa[2], Dr Paulino Pérez-Rodríguez[6], Dr Abhishek Rathore[4], Dr Star Yanxin Gao[1], Dr Susan McCouch[1]

Collaborating organisations: [1]Cornell University; [2]CIMMYT; [3]UWA; [4]ICRISAT; [5]ICAR-IARI; [6]Colegio de Postgraduados, Mexico

Much of the world's population growth will occur in regions where food insecurity is prevalent, with large increases in food demand projected in regions of Africa and South Asia. While improving food security in these regions will require a multi-faceted approach, improved performance of crop varieties in these regions will play a critical role. Current rates of genetic gain in breeding programs serving Africa and South Asia fall below rates achieved in other regions of the world. Given resource constraints, increased genetic gain in these regions cannot be achieved by simply expanding the size of breeding programs. New approaches to breeding are required.

The Genomic Open-source Breeding informatics initiative (GOBii) and Excellence in Breeding Platform (EiB) are working with public sector breeding programs to build capacity, develop breeding strategies, and build breeding informatics capabilities to enable routine use of new technologies that can improve the efficiency of breeding programs and increase genetic gains. Simulations evaluating breeding strategies indicate cost-effective implementations of genomic selection (GS) are feasible using relatively small training sets, and proof-of-concept implementations have been validated in the International Maize and Wheat Improvement Center (CIMMYT) maize breeding program. Progress on GOBii, EiB, and implementation of GS in CIMMYT and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) breeding programs are discussed, as well as strategies for routine implementation of GS in breeding programs serving Africa and South Asia.

The maize research is supported by The Bill and Melinda Gates Foundation, Howard G. Buffett Foundations, USAID, and the CGIAR Research Program MAIZE.

The chickpea research is supported by the Department of Science and Technology as a part of AISRF Project and Department of Biotechnology (Government of India). It is part of the CGIAR Research Program on Grain Legumes and Dryland Cereals.

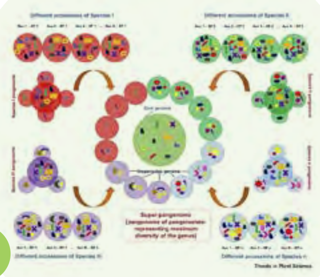
21: A maize crop in Mexico.

22: A chickpea flower in the field.

Super-Pangenome by integrating the wild side of a species for accelerated crop improvement

Project team: Adjunct Professor Rajeev Varshney[1,2] (project leader; r.k.varshney@cgiar.org), Dr Aamir Khan[1,2], Dr Vanika Garg[2], Dr Manish Roorkiwal[2], Dr Agnieszka Golicz[3], Professor Dave Edwards[1]

Collaborating organisations: [1]UWA; [2]ICRISAT; [3]The University of Melbourne



23

In this research project, researchers gave a concept of the “Super-Pangenome”. Pangenome studies conducted to date have so far have been limited mainly to one species and mostly cultivated accessions. The challenge with the current pangenomes is lack of representation of genomic diversity at the genus level.

Crop wild relatives possess unearthed genetic diversity that has been lost during domestication and breeding. Pangenomics of crop wild relatives is the way forward to catalogue the complete gene repertoire of a genus.

The super-pangenome is the approach of developing a pangenome of the pangenomes of different species for a given genus. Currently available methods and tools to develop pangenomes are mainly restricted to bacterial (prokaryotic) genomes. It is important now to develop novel, effective, and user-friendly tools for the development of super-pangenomes for crop (eukaryotic) genomes. The pangenome provides genomic variations in the cultivated gene pool for a given species. However, as the crop’s gene pool comprises many species, especially wild relatives with diverse genetic stock, here authors suggest using accessions from all available species of a given genus for the development of a more comprehensive and complete pangenome, which they referred to as a Super-Pangenome.

The Super-Pangenome provides a complete genomic variation repertoire of a genus and offers unprecedented opportunities for crop improvement. This research article focussed on recent developments in crop pangenomics, the need for a Super-Pangenome that should include wild species, and its application for crop improvement breeding following functional validation studies of the genes.

This research is supported by the AISRF project from the Department of Biotechnology, Government of India, and Tropical Legumes project funded by the Bill and Melinda Gates Foundation, JC Bose National Fellowship and DST.

23: Approaches for the construction of a Super-Pangenome.

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], Dr Rajneet Uppal[2], Andrew Carmichael[2], John Bromfield[2], Reuben Burrough[2], Tony Napier[2], Dr Suman Rakshit[3], Dr Katia Stefanova[3], Dr Bob French[4], Dr Ian Pritchard[4]

Collaborating organisations: [1]UWA; [2]NSW DPI; [3]SAGI West; [4]DPIRD

This is a GRDC-funded national project aiming to improve genetic gain for heat stress tolerance in canola. UWA co-ordinates this national project with a sub-contract to NSW Department of Primary Industry (NSW DPI) at Wagga Wagga. The research involves controlled-environment and field-based experiments to discover and validate genes for canola heat stress tolerance.

In 2020, a prototype heat-stress facility and protocol for heat tolerance screening was developed at UWA Field Station at Shenton Park. In this facility, experiments were conducted to assess the heat tolerance of 200 canola genotypes. An open day was held in early September 2020 to demonstrate the canola heat tolerance screening in action. The heat-tolerant germplasm identified will be re-assessed in 2021 and further validated in future field experiments. The genomic DNA from leaf tissues of these 200 genotypes was extracted for whole genome genotyping.

Also in 2020, field-based experiments were conducted in portable heat chambers at NSW DPI Wagga Wagga. Twelve genotypes were assessed with three treatments in three-row plots. Multi-environmental field trials were conducted to validate and demonstrate the heat tolerance of selected canola germplasm. These trials were designed by experts in GRDC Statistics for Australian Grains Industry project (SAGI-West). Thirty genotypes were sown across five times of sowing with two replicates at three locations across southern Australia: Narrabri and Leeton in NSW and Merredin in WA. Measurements were taken in a timely manner, including hourly temperatures, date of flowering and date of maturity. Plants were harvested and the measurements of seed yield related traits are ongoing.

At the end of this project, we will confirm the value of heat stress tolerant canola genotypes in multi-environment field trials, and find functional markers and haplotypes associated with heat stress tolerance. This information will be provided to canola breeders for breeding of heat stress tolerant canola cultivars.

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

24: The open day was held on September 8 at the UWA Shenton Park Field Station for demonstration of the canola heat tolerance screening in action, with 28 canola researchers and industry representatives in attendance.

25: Professor Cowling answers questions at the Open Day to demonstrate the canola heat tolerance screening in action.

Pre-breeding of canola and peas

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

Collaborating organisation: [1]UWA

Since 2000, NPZ Lembke in Germany has funded pre-breeding of spring canola and field peas at UWA. In addition to releasing several canola varieties with high commercial value to Australian canola producers, this long-term collaboration has developed new rapid-breeding methods in self-pollinating crops.

An important milestone was achieved in 2020 in the spring canola pre-breeding project based at UWA. This global breeding project, led by UWA, was a joint collaboration of NPZ breeders in Australia, Germany and Canada. The project began at UWA in 2012 by intercrossing spring canola varieties from Canada, Europe and Australia. Four cycles of recurrent selection then occurred with field testing in Canada and Australia in 2014 (cycle 1), 2016 (cycle 2), 2018 (cycle 3) and 2020 (cycle 4). Results in 2020 confirmed that the population had superior yield, seed oil and protein, and blackleg disease resistance, with high genetic correlations across Australia and Canada, and low rates of inbreeding and high future potential for genetic gain. Results are of commercial significance to NPZ spring canola breeders in the northern and southern hemispheres.

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

The results indicate an average increase in grain yield of 4 per cent per year from cycle 1 to cycle 4. Similar rapid improvements were observed in seed oil and protein, and blackleg disease resistance. The population retains high genetic diversity and therefore has long-term potential for genetic improvement.

Similar methods are currently being applied to field peas in a new PhD project of Felipe Castro Urrea. This project will evaluate new genomic selection methods to rapidly improve field peas for stem strength, black spot disease resistance, and grain yield, also with the support of NPZ Lembke in Germany.

This research is supported by UWA and NPZ Lembke.

26: Field trials in the UWA-NPZ spring canola pre-breeding project Photograph taken September 2020 near Boyup Brook, Western Australia.

Super-adaptive plant plasticity to light and disease: Perspectives from natural variation in *Camelina sativa*

Project team: Maria Purnamasari[1], Dr Janine Croser[1] (project leader; janine.croser@uwa.edu.au), Professor William Erskine[1], Dr Judith Lichtenzveig[1], Professor Martin Barbetti[1]

Collaborating organisation: [1]UWA

Plant performance in the field is determined by environmental factors. An individual plant genotype can produce multiple phenotypes in response to changes in environmental conditions; this is known as phenotypic plasticity. *Camelina sativa* (L.) Crantz (Brassicaceae) is an oilseed crop with value in the production of functional foods, industrial oils and biofuel. However, current knowledge is incomplete regarding this plant's plasticity to two economically important agricultural challenges: shade and Sclerotinia rot (SR; disease caused by a broad-host pathogen *Sclerotinia sclerotiorum* (Lib.) de Bary).

The purpose of this research was to a) determine the population structure within a panel of Camelina genotypes and b) use a Camelina-shade-*S. sclerotiorum* model system to study plant plasticity in different environments to identify the key genetic causes underlying these responses. This project provides information regarding the crops' genetic diversity, response to light spectral composition, plasticity to shade and response to major Brassicaceae pathogens.

This study contributes substantially to our understanding of plant defence regulation under shade, the associated genomic locations, the links between shade avoidance syndrome and defence, and the natural variation in a plant model for defence under shade that will serve as useful resource for further studies.

This research is supported by the Indonesia Endowment Fund for Education Scholarship.

27: Camelina seedling growth at UWA under different LED spectra.

28: Camelina response to *Sclerotinia sclerotiorum* inoculation.

Narrow-leafed lupin pre-breeding: unravelling the genetic control of flowering time

Project team: Professor Wallace Cowling[1] (project leader; wallace.cowling@uwa.edu.au), Dr Candy Taylor[1], Dr Renu Saradadevi[1], Julian van der Zanden[1], Dr Matthew Nelson[2], Dr Jens Berger[2], Dr Lars Kamphuis[2,3], Professor Karam Singh[2,3], Dr Darshan Sharma[4], Dr Matthew Aubert[5], Dr Dion Bennett[5]

Collaborating organisations: [1]UWA; [2]CSIRO; [3]Curtin; [4]AGT

Flowering time represents one of the most significant traits affecting the adaptation of annual crops to agricultural environments.

A single gene (*Ku*) has been used since the 1960s in the breeding of narrow-leafed lupin crops for warm short-season climates, such as those in the northern Western Australian wheat belt where lupin production has historically been very strong. However, in order to expand the lupin industry in other regions of Australia and to provide growers with greater flexibility, it is important that more flowering time genes are made available to breeders and that new varieties are developed with a wider range flowering times that are more appropriate for other environments and/or emerging agronomic practices, such as dry-seeding.

Our research group recently identified two new variations of the *Ku* gene in European varieties and wild narrow-leafed lupins from the Mediterranean. Some European varieties have a variation called *Julius*, which creates an equally, if not earlier, flowering time than *Ku*. In 2020, a prototype other variation was observed in a wild line originating from Israel and creates a novel mid-season flowering time that is potentially valuable for mid-high rainfall environments. Both new variations of *Ku* are associated with different genetic backgrounds that are of potential value to Australian lupin breeding.

In 2020, we conducted our second field-based trial to evaluate the inheritance and performance of these two new flowering time gene variations. The plots within this trial included sweet and soft-seed fourth-generation (F_4) progeny from crosses between traditional Australian varieties and others with the two new *Ku* variants. A range of traits were evaluated in addition to flowering time, including height, vigour, flower colour, foliage colour, and shattering susceptibility. The trial was conducted in partnership with Australian Grain Technologies (AGT) at their breeding trial site in Mumberkine in WA and was funded by a Council of Grain Growers Organisation (COGGO) grant.

In addition to this field-based work, our research group developed a new genetic marker assay to differentiate the *Ku* variations in the laboratory in 2020. This work was completed by Master's student Julian van der Zanden, who was recipient of a UWA Agribusiness Connect Scholarship funded by Royalties for Regions. The assay reliably identifies the alleles of *Ku* present in individual plants and provides confident predictions of flowering time, therefore improving the efficiency of research and breeding.

Our group has been working to understand how genetic variation at *Ku* affects the response of narrow-leafed lupin to environmental signals that promote flowering. In this research, we have been comparing the flowering times of a large and diverse set of narrow-leafed lupins under warm and cool conditions and examining the responses of wild *vs* domesticated lines. In addition, we are comparing how these responses differ amongst wild populations throughout the Mediterranean, which will potentially help identify useful germplasm for future breeding.

This research is supported by the COGGO Research Fund, GRDC, and UWA.

29: UWA Masters student Julian van der Zanden examining flowering time in narrow-leafed lupins in the field.

30: Mumberkine-based field trial to assess performance of two new narrow-leafed lupin flowering time genes.

Shoot and root growth of castor bean in response to soil salinity

Project team: Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au), Dr Yinglong Chen[1], Gilang Bintang Fajar Suhono[1], Dr Yinghao Li[2]

Collaborating organisations: [1]UWA; [2]Shenyang Agricultural University

Soil salinity is a serious threat to agriculture worldwide, which is increasing due to natural salinisation and increased irrigation. Castor bean (*Ricinus communis L.*) is an industrial oilseed crop.

This study evaluated root and shoot responses of two castor bean genotypes (Zibo imported from China and Freo from Western Australia) to 0, 100 and 200mM sodium chloride (NaCl) grown in deep PVC tubes in a glasshouse. Salt stress was induced gradually, with 25mM NaCl added every second day from 21 days after sowing (DAS) until the pre-determined salinity level was reached. Plants were harvested for assessments at 112 DAS.

In both genotypes, the 200mM NaCl treatment significantly reduced plant height, stem diameter, number of fully expanded leaves, leaf area, shoot and root biomass, total root length, photosynthetic traits, chlorophyll content, K^+ concentration, K^+/Na^+ ratio and increased Na^+ concentration, relative to the control. The 100mM NaCl treatment had litter effect on both genotypes indicating their tolerance to moderate salinity stress (100mM NaCl). Castor bean plants showed salinity tolerance mechanisms such as retaining Na^+ in old tissues, limiting Na^+ uptake by roots, limiting Na^+ translocation into shoots, and maintaining high K^+/Na^+ ratio in young leaves.

This research is supported by UWA and the Indonesia Endowment Fund for Education.

31: Comparison of castor bean genotypes Zibo and Freo under three salinity treatments (control, 0mM NaCl; S1, 100mM NaCl; S2, 200mM NaCl) at 112 days after sowing.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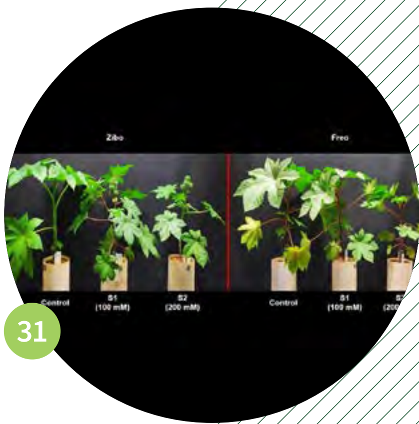

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A platform for rapid genetic gain in pulses

Project team: Dr Janine Croser[1] (project leader; janinecroser@uwa.edu.au), Dr Judith Lichtenzveig[1], Professor William Erskine[1], Dr Maria Pazos-Navarro[1], Dr Richard Bennett[1], Sabrina Tschirren[1], Christine Munday[1], Simone Wells[1]

Collaborating organisations: [1]UWA; Pulse Breeding Australia; Australian Grains Genebank; CSIRO

This research has delivered a robust platform for accelerated Single Seed Descent (aSSD) to the pulse pre-breeding and breeding community. The platform is for the four major cool season legumes faba bean, chickpea, lentil and field pea. Researchers and breeders have utilised the aSSD platform to progress from F2:6 and to undertake out-of-season cycling (F2:4). We have undertaken 'cross to Recombinant Inbred Lines (RILs)' to rapidly progress herbicide tolerant (HT) populations to fixation. Combining aSSD with marker-assisted selection (MAS) has resulted in highly efficient HT screening of chickpea and field pea lines.

Deployment of the aSSD platform has transformed the ability of the pulse industry to rapidly deliver adapted germplasm with traits including salinity, heat and drought tolerance, herbicide, pest and disease resistance, better pod retention, early flowering and maturity.

GRDC investment in wild *Cicer* species collection efforts have delivered 131 new *Cicer echinospermum (Ce)* accessions into Australia. We evaluated genetic compatibility of a subset of *Ce* accessions and chickpea to assess the potential for gene introgression from this wild species to the cultivar. Our observations point to intra-specific karyotype diversity in *Ce* and a full spectrum in inter-specific compatibility at chromosomal pairing in cv x *Ce* hybrids. Across the past year, we have taken the F3 populations to F4.

This research has also delivered four 'cultivated x *Ce*' populations for *Ce* selected from high elevation sites to contribute to efforts in developing chilling tolerant cultivars. Mindful of the opportunities offered by newly collected *Cicer reticulatum* (*Cr*) accessions collected from high elevations, we also developed two cv x *Cr* hybrids. The UWA Rapid Gene Introgression platform, adapted from the aSSD research, has facilitated rapid delivery of F4 families. We are now analysing data from chilling-exposure experiments incorporating both cultivated and wild-derived hybrid material.

The development of novel wild-derived hybrid germplasm and technology to rapidly cross and fix alleles, underpinned by comprehensive germplasm characterisation, will enable researchers to effectively use the new germplasm within genetic improvement programs.

This research is supported by UWA and the GRDC.

32: Faba beans RILs growing under aSSD conditions at UWA.

33: Cicer hybrid RILs growing under LEDs at UWA.

A significant increase in rhizosheath carboxylates and greater specific root length in response to terminal drought is associated with greater relative phosphorus acquisition in chickpea

Project team: Manish Sharma[1], Dr Jiayin Pang[1], Zhihui Wen[1], Axel De Borda[1], Hee Sun Kim[1], Yifei Liu[1], Emeritus Professor Hans Lambers[1], Professor Megan Ryan[1], Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au)

Collaborating organisation: [1]UWA

Drought and nutrient uptake are two major challenges for agricultural production. The aims of this research were to:

- Investigate the effect of water stress under low phosphorus on phosphorus acquisition and physiological phosphorus use efficiency among four chickpea genotypes, and
- Identify genotype/s with a faster relative growth rate and phosphorus acquisition rate under water stress and low phosphorus.

Water stress imposed at the flowering stage reduced shoot and root growth, root mass ratio, and shoot phosphorus content, while specific root length and water use efficiency increased. Genotype ICC 2884 maintained stomatal conductance and photosynthesis rate until it reached a lower soil water content than did the other three genotypes. In addition, genotype ICC 2884 had a faster relative phosphorus acquisition rate.

Based on this research, ICC 2884 can be used as a promising parental genotype in chickpea breeding programs targeted at developing cultivars for low phosphorus soils and drought environments. Further research is required to be done under field conditions.

This research is supported by UWA.

34: Masters student Manish Sharma at a UWA glasshouse.

Response of chickpea genotypes with contrasting root morphological traits to phosphorus placement

Project team: Sean Squires[1], Dr Yinglong Chen[1], Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au)

Collaborating organisation: [1]UWA

Chickpea (*Cicer arietinum*) is a valuable legume crop for human nutrition due to its high protein content. A glasshouse study investigated the relationship between the root morphological characteristics of two contrasting chickpea genotypes and phosphorus (P) placement methods (banded versus top-dressed) using 1.5m deep rhizoboxes. The study showed that P placement had a significant impact on the growth and development of chickpea plants.

Banded P improved soil exploration and promoted thinner roots efficient in using P for the growth with high P-use efficiency compared to top-dressed P treatment. Genotypic differences were more pronounced for shoot traits than for root traits, with no major interactions between genotype and P placement treatments for most traits. Further research will study the effect of P placement on chickpea under field conditions, and investigate how cultivars with other contrasting root traits (i.e. carboxylate exudation and mycorrhizal responsiveness) interact with P placement to affect plant growth and production.

This research is supported by UWA and UWA's Basil Stone Award and Edith Easthope Science Scholarship.

35: Honours student Sean Squires inspecting chickpea responses to phosphorus placement using deep rhizoboxes.

Functional genomics of chickpea to enhance drought tolerance

Project team: Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au), Professor Harvey Millar[1], Dr Jiayin Pang[1], Dr Elke Stroeher[1], Dr Santiago Signorelli Pollolo[1], Adjunct Professor Rajeev Varshney[2]

Collaborating organisations: [1]UWA; [2]ICRISAT; The ARC Centre of Excellence in Plant Energy Biology

Chickpea has become the second most important grain legume globally, and the largest pulse crop in Australia in rotation with cereals. It is a major pulses crop in developing countries especially in India, providing a rich source of protein, carbohydrates and minerals. Water shortage during the reproductive phase (terminal drought), is a major abiotic stress limiting chickpea production worldwide. Therefore, improving drought tolerance in chickpea is critical for improving its productivity in the context of changing climatic scenarios.

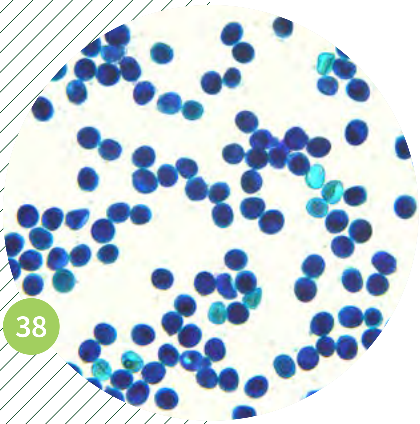
As a part of a long-term research partnership between UWA and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) over the last two decades, the project funded by Australia-India Strategic Research Fund Australia-India (AISRF) aims at the development of genome and gene-linked proteomics, metabolomics and transcriptomics associated with drought tolerance.

In 2020, a large-scale glasshouse experiment was set up at the UWA in 1m tall PVC tubes, using the field soil from the WA grain-belt. The aim was to understand the root morphology, proteomic and metabolomic processes associated with drought resistance during decreasing soil water content imposed at reproductive stage with four chickpea genotypes. Four chickpea genotypes including two drought tolerant ones and two drought sensitive ones were included in the study. Terminal drought stress was imposed at the early podding stage, 3.5 months after planting, with another set of plants kept well-watered as the control. Soil water content in each pot was monitored closely using a framed balance. When soil water content in the drought stressed plants reduced to 30 per cent of the field capacity, plants were harvested and root subsamples were taken from the top 30 cm and bottom 30cm of each pot. Those samples will be processed and analysed for proteomics and metabolomics. The proteins and metabolites identified from the project, which are associated with drought tolerance, will provide useful markers for chickpea breeding program.

This research was supported by the Australia-India Strategic Research Fund.

36: Members of the research team at a UWA glasshouse.

37: The drought-tolerance chickpea experiment was set up at a UWA glasshouse in 1m tall PVC tubes.



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Advancing hybrid wheat breeding using genomics and molecular biology approaches

Project team: Professor Ian Small[1] (project leader; ian.small@uwa.edu.au), Dr Joanna Melonek[1], Pascual Perez[2], Professor Nils Stein[3], Professor Curtis Pozniak[4]

Collaborating organisations: [1]UWA; [2]Groupe Limagrain; [3]University of Göttingen, Germany; [4]University of Saskatchewan, Canada

Hybrid crops grow faster, produce more than conventional varieties and show more stable yield under varying conditions. The potential of hybrid breeding in wheat was recognised by plant breeders at the end of the 19th century but has been under-exploited because of the difficulties in producing hybrid seed on an industrial scale. The major limiting factor is the absence of an efficient way to control self-pollination. In many other crops, including maize, rice and brassicas, cytoplasmic male sterility (CMS) and restorer of fertility (Rf) genes are used for this purpose. However, wheat lacks effective Rf genes that can ensure maximal seed set of F1 hybrids. Thus, the main goal of our project is to predict, clone and validate Rf gene candidates that will be applied in wheat hybrid breeding programs.

In our studies, we apply genomics approaches to perform genome-wide analyses of the family of Restorer-of-fertility-like (RFL) genes in wheat and its close relatives as well as in commercial wheat lines used in ongoing hybrid wheat breeding programs led by our main collaborator Groupe Limagrain – the third largest seed producing company in the world. The obtained genomics information is then applied to predict candidates for restorer genes. The ability to restore fertility of the candidates is validated in our laboratory by characterisation of wheat transformants generated by colleagues from Groupe Limagrain by pollen staining assays and plant molecular biology techniques including RNA-Seq and protein analyses.

In 2020, our analysis of the RFL gene family in the first wheat pangenome was published in *Nature* in collaboration with Professor Curtis Pozniak (University of Saskatchewan) and Professor Nils Stein (IPK Gatersleben) within the 10+ Wheat Genomes project - a global partnership governed by Wheat Initiative. In addition, the results of our studies on cloning and molecular characterisation of Rf1 and Rf3 restorer genes in wheat (manuscript accepted for publication in *Nature Communications*) formed the basis for a patent application "New gene responsible for cytoplasmic male sterility".

By providing 20 per cent of global dietary energy, wheat is one of the most important grain crops cultivated worldwide, and together with maize and rice, contributes 70 per cent of global crop production. With 21 million tonnes produced annually, and a gross value reported at nearly AU$6 billion, the wheat industry makes an important contribution to the Australian economy. To guarantee future yield gains, rapid technological improvements that will pave the way for the development of high-yielding hybrid wheat varieties will be crucial.

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

38: Wheat fertile (dark blue) and sterile (light blue) pollen grains stained with Alexander's stain.

39: Spikes of fertile wheat plants with visible anthers and a sterile plant (second from left) without anthers.

Application of zinc and biochar help to mitigate cadmium stress in bread wheat raised from seeds with high intrinsic zinc

Project team: Associate Professor Muhammad Farooq[1,2] (project leader; farooqcp@gmail.com), Dr Aman Ullah[1], Dr Muhammad Usman[1], Hackett Professor Kadambot Siddique[2]

Collaborating organisations: [1]Sultan Qaboos University; [2]UWA

Cadmium (Cd) contamination in soil negatively impacts crop productivity, grain quality, and human health. Wheat seeds, with different concentrations of intrinsic zinc (Zn): low Zn (35 mg kg^{-1}), medium (42 mg kg^{-1}), and high Zn (49 mg kg^{-1}), were planted in artificially contaminated soil (10 mg Cd kg^{-1} soil). Zinc (5 g kg^{-1}) and biochar (20 g kg^{-1} soil) were applied alone or in combination at sowing.

Plants from high intrinsic Zn seeds performed better under Cd stress with the application of soil amendments than seeds with low or medium intrinsic Zn levels. The combined application of Zn and biochar had the highest increases in grain yield (9.51 per cent) and grain Zn concentration (12.2 per cent), relative to the control (no Cd, no Zn, and no biochar). This treatment also decreased the Cd concentrations in straw (7.1 per cent) and grain (95.6 per cent). The sole application of Zn or biochar improved wheat productivity and grain Zn concentration and deceased grain Cd concentration under Cd stress, but more improvements resulted from the combined application of Zn and biochar. Plants grown from seed with high Zn were better able to tolerate Cd stress than the plants raised from seeds with medium and low Zn levels.

This study has found that the combined application of biochar and zinc can mitigate stress in wheat caused by the heavy metal cadmium. Cadmium reduces the growth, yield, and zinc concentration in wheat grain due to oxidative stress. Its accumulation in soil can cause significant health risks to humans if it is introduced into the food chain via crops. The research shows that the combined application of biochar and zinc to cadmium-contaminated soil improved both yield and grain Zn concentration, and reduced Cd concentrations in grain.

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

40: A wheat field in the grain belt.

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]

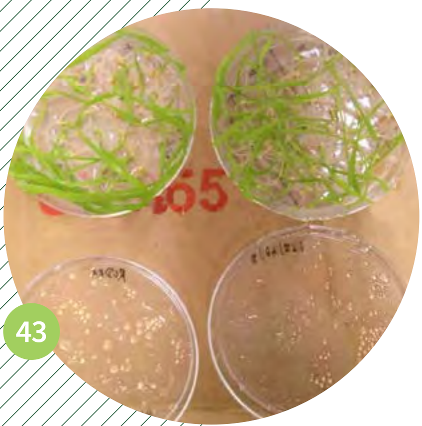
Collaborating organisation: [1]UWA

Bread wheat (*Triticum aestivum* L.) is a major staple cereal crop accounting for nearly 50 per cent of the global grain trade. However, it is quite sensitive to high temperature, and heat stress during the reproductive stage results into fewer and smaller grains and subsequent yield losses. This is the result of disruption to source-sink relationships, abnormal ovary development, lower pollen viability, reduced pollen tube growth and fewer viable embryos. Genetic mapping studies have revealed numerous genomic regions called Quantitative Trait Loci (QTL) for heat stress tolerance and associated traits, but few major effect QTL, owing to the complex nature of heat stress tolerance. However, most mapping studies are confined to reproductive and post-reproductive stages. To the best of our knowledge, heat stress at meiosis in reproductive tissue has not been tested extensively for heat stress tolerance and QTL genetic mapping. This study aimed to test the effect of high temperature during meiosis on the outcomes of meiosis, and how this affects seed yield (seed number and weight) in different segments of the spike. We will use conditions that mimic heat waves during meiosis (early booting stage) in the field, and supply ample water to avoid drought stress.

In the first experiment in 2020, 30 genotypes were screened at the meiotic stage under heat stress and control conditions. Heat treatment during meiosis reduced grain yield and grain number on the main stem. Furthermore, significant genetic variation was observed among the genotypes for grain yield and grain number in the main stem, and potential heat stress tolerant and sensitive cultivars have been identified. The contrasting genotypes (i.e. the most tolerant and sensitive ones) will serve as parents for generating mapping populations, which in future experiments will allow us to discover genomic regions (QTLs) that govern heat stress tolerant traits. The crossing programme has begun and after the F2 a rapid generation technique (tissue culture based) will be employed to develop Recombinant Inbred Lines for QTL mapping and validation.

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

41: PhD student Mukesh Choudhary investigating the heat stress tolerance associated traits in wheat.



Development of near isogenic lines and fine-mapping of herbicide (metribuzin) resistance in wheat (*Triticum aesitivum* L.)

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 crop species in the world. It is the biggest agricultural commodity in Australia in terms of yield and trade. However, drought, weed infestation, and evolving pathogens are constantly affecting wheat yield. Weeds can cost Australian agriculture between $2.5 billion and $4.5 billion per annum. Therefore, controlling weeds using any means is necessary for good crop harvest. Herbicides are used to kill weeds, which is one of the most effective weed-controlling strategies. Among others, metribuzin is used as a broad-spectrum, and is widely used in dry-land farming systems in Australia. However, controlling weeds using metribuzin in wheat field is one of the difficult tasks as wheat has a narrow safety margin for metribuzin. Hence, identification of appropriate herbicide resistance genetic sources is a prerequisite for successful weed control strategy. Therefore, this study aims to dissect such resistance sources genetically through the development of nearly isogenic lines (NILs), NIL characterisation, and fine mapping.

Metribuzin resistance QTL have been successfully mapped in wheat by Bhoite et al. (2018) and Xu et al. (2020). However, molecular marker information associated with QTL mapping study has some limitations which may not be usable directly for gene pyramiding, tagging and marker-assisted selection programs. Hence, genetic dissection of QTLs is paramount through the characterisation and utilisation of NILs.

In 2020, 24 putative NIL pairs targeting a 4A locus, nine putative NIL pairs targeting a 3A locus and four lines combining the 4A and 3A loci were developed through the process of repeated selfing using the principle of heterogeneous inbreed family method (HIF) (Tuinstra et al. 1997) combined with a fast generation cycling system (FGCS) (Yan et al. 2017) and marker assisted selection (MAS). Markers were used from the identified QTL regions to select the individual heterozygotes until F7 generations. In 2021, developed putative NILs will be evaluated. Confirmed NIL pairs will be scrutinised through transcriptomic and proteomic studies. NIL pairs different in refined QTL regions will be used to identify candidate genes and functional markers.

This research is supported by the UWA RTPFI - RTP International Fees Offset and UPAIS (University Postgraduate Award).

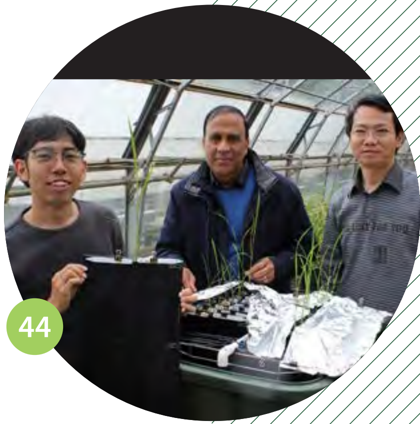
42: Contrasting NIL pairs for senescence are seen clearly during plant evaluation in the F8 generation. +NIL possesses the alleles of metribuzin resistance and -NIL possesses the alleles of metribuzin susceptibility for a 4A locus.

43: Regenerating plantlets from selected heterozygous lines using a FGCS. Left, the lids and right, the seedlings are ready for transplanting to the soil after 15 days of embryo nurturing in artificial media.

The response of lateral roots to root tip excision in rice using a semi-hydroponic phenotyping system

Project team: Tsubasa Kawai[1,2], Dr Yinglong Chen[1], Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au)

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



Rice develops fibrous root system comprising of a seminal root, numerous crown roots (parent roots) and their lateral roots. Lateral root development is promoted when parent root growth is inhibited. One such factor inhibiting parent root elongation is soil compaction, which is heterogeneously distributed and causes mechanical impedance of parent root growth. It triggers lateral root development in the upper loose soil in various plant species. Compensatory growth of lateral roots facilitates the uptake of water and nutrients by maintaining sufficient total root length, which in turn contributes to shoot growth maintenance.

In this project, response of root system to root tip excision on parent roots in rice, which mimics the damage caused by the compact soils, is analysed with the semi-hydroponic phenotyping system. First, root system architecture was characterised in 10 Australian, five Japanese cultivars and five mutants. This study showed large genotypic variation and strong correlations among shoot and root traits.

Based on the phenotypic observations, six rice genotypes with contrasting root systems were selected and subjected for the root tip excision. The root tip excision inhibited deeper rooting but enhanced lateral root development. Comparison of shoot and root phenotypic traits showed compensatory root growth in response to root tip excision. This study provides a clue for the improvement of root system to tolerate soil compaction in rice.

This research is supported by UWA and the Japanese Society for the Promotion of Sciences.

44: PhD student Tsubasa Kawai with Hackett Professor Siddique and Dr Yinglong Chen inspecting rice plants grown in the semi-hydroponic system.

Developing sustainable cropping systems for cotton, grains and fodder

Project team: Dr Janine Croser[1] (project leader; janine.croser@uwa.edu.au), Professor William Erskine[1], Dr Theo Pfaff-Lichtenzveig[1], Sabrina Tschirren[1], Dr Maria Pazos-Navarro[1], Dr Judith Lichtenveig[1]

Collaborating organisation: [1]UWA

UWA researchers have been working closely with NACRA staff in the Kununurra Ord Valley region to fast-track agronomic and genetic improvement of the functional food species chia and quinoa. The research involves:

- The development of robust intraspecies crossing methodology in both species
- Controlled environment experiments to determine methods to grow these plants year-round, thus speeding the fixation of genes after crossing
- Field trials in Kununurra and phenotyping to evaluate the value of new combinations, and
- Use of sequencing data to determine hybridity.

Highlights include the development of:

- Highly successful intraspecific crossing methodology for both species
- Precocious germination techniques for both species
- Controlled environment protocols for year-round growth and turnover of >4 generations per year in both species, and
- Appropriate genomic methodology to identify true hybrids.

In 2021, we expect to deliver a large number of recombinant inbred lines developed as a result of the UWA crossing and generation cycling efforts. These lines will be assessed in the field at Kununurra in 2021/22. This research is targeted at developing appropriate and profitable cotton break crops for sustainable farming in the region.

This research is supported by CRC-P Lead Agency NACRA.

45: Sabrina Tschirren with chia plants growing under fully controlled environment conditions in the UWA Plant Growth Facility.

46: Dr Theo Pfaff-Lichtenzveig inspecting quinoa plants growing under fully controlled conditions in the UWA Plant Growth Facility.

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

Project team: Mohammad Islam[1,2], Dr Zakaria Solaiman[1] (project leader; zakaria.solaiman@uwa.edu.au), Professor Zed Rengel[1], Mr Paul Storer[3], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Bangladesh Jute Research Institute; [3]Troforte Innovations Pty Ltd; DPIRD, FFLI; Premium Hemp Australia; 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 determine the effects of biological and standard chemical fertilisers on soil biological fertility, nutrients availability and hemp productivity
- To evaluate the water use efficiency and effect of different water regimes on selected hemp varieties, and
- To evaluate locally available and imported varieties of industrial hemp regarding various phenotypic, physiological and yield traits.

In 2020, an experiment was conducted in pots in controlled environment room at the plant growth facilities of The University of Western Australia to determine the effect of fertilisation on industrial hemp.

Two varieties Han FNQ and Morpeth, which were selected based on germination and early growth trials of the previous year's experiment, were used to test the effect of rock mineral fertiliser and microbes and their combination along with control (no fertilisation). Plants were raised and harvested at 30 days and 90 days after sowing. Several growth indices along with Soil Plant Analysis Development (SPAD) readings were recorded. Root growth indices and microbial colonisation will be also measured. Major macro- and micro-nutrients in seeds and shoots were also measured using inductively coupled plasma optical emission spectroscopy (ICP-OES).

Previous studies reported that rock minerals containing vital nutrients were frequently added to agricultural soils (Carson et al. 2009; Manning 2010). The weathering of these minerals in soils is boosted by microbial activity. Associations of specific microorganisms with specific rock minerals (Gleeson et al. 2010; Hutchens et al. 2010) escalate the nutrient release rate from minerals (Colombo et al. 2014). Studies also reported that hemp needs lower fertilisation than most major crops such as wheat, barley and canola.

Therefore, this experiment will provide a rigorous scientific assessment of the efficacy of novel mineral-based biofertiliser in industrial hemp-based cropping systems.

This research is supported by UWA and the RTP PhD Scholarship.

47: Effect of mineral-based biofertiliser on industrial hemp (*Cannabis sativa* L.).

48: SPAD readings for measurements of leaf N and chlorophyll content in industrial hemp.

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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]

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.

This 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 on UWA Farm Ridgefield. Land managers, including those affiliated with Wheatbelt NRM and the Shires of Brookton and Pingelly, have learned how to install permeable biomass (waste organic matter) barriers placed strategically among recent plantings of native trees and pasture species to fast-track soil restoration on degraded pockets of land within the farm. The trees at this site were planted in collaboration with UWA Farm Ridgefield and Greening Australia as part of an ongoing land restoration program. The field demonstration is based on success of an existing small-scale initiative at Treōwstede near Brookton.

Field days have provided hands-on experience to participants during different stages of the project from installation to monitoring. The practices being trialled involve permeable biomass (waste organic material) barrier wells and walls to fast-track restoration of degraded soil, in this case, 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.

Progress during 2020 included the establishment of the holes and trenches prior to installation of the permeable biomass barriers. Field days, including hands-on participation, were also conducted to demonstrate and explain these techniques to the local farming community.

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

49: Work conducted at UWA Farm Ridgefield for the farm demonstration project.

Impact of subterranean clover seed harvesting on soil properties

Project team: Professor Megan Ryan[1] (project leader; megan.ryan@uwa.edu.au), Associate Professor Phillip Nichols[1], Adjunct Professor Ann Hamblin[1], Bradley Wintle[1], Dr Andrew Guzzomi[1], Dr Kevin Foster[1], Wesley Moss[1], Daniel Otwani[1], Dr Joanne Wisdom[1]

Collaborating organisations: [1]UWA; Bell Pasture Seeds

Daniel Otwani commenced his Master's research in March 2020 as part of the Agrifutures-funded project "Profitable and environmentally sustainable subclover and medic seed harvesting". The vacuum harvest of subclover seed (utilising a Horwood Bagshaw Clover Harvester) was studied on a commercial farm in southern Western Australia. Analysis of soil physicochemical properties revealed that soils after a vacuum harvest process were more predisposed to wind erosion than before harvest. Additionally, soil nutrient concentrations were higher in the finer soil fractions, which increased in abundance after harvest and were more prone to erosion. A total of 28 per cent of harvestable seed was not recovered by the vacuum harvest process.

This study revealed that the current subclover harvesting process is inefficient and needs a rethink to move towards greater sustainability.

This research is supported by AgriFutures Australia and an Australia Awards Scholarship.

50: Project team during final student research presentation seminar in November 2020. Standing (left to right): Associate Professor Phillip Nichols, Master's student Daniel Otwani, Adjunct Professor Ann Hamblin, Professor Megan Ryan and Bradley Wintle.

51: Horwood Bagshaw Clover Harvester during harvest testing in a subclover seed paddock in January 2020.

Modification of plant sterol composition for crop protection

Project team: Professor Jacqueline Batley[1] (project leader; jacqueline.batley@uwa.edu.au), Dr Jing Li[1]

Collaborating organisations: [1]UWA; Murdoch University; University of Tasmania; Texas Tech University, USA

This research project is developing a novel biotechnological strategy to control insects for crop protection. The strategy is based on the principle that these pests rely on converting host phytosterols to cholesterol, which is essential for their growth and development.

The project involves modifying plants to produce non-utilizable sterols, which will be unable to support insect growth and reproduction, but will nevertheless function normally in plants.

Using a plant model system, we have successfully modified Arabidopsis plants synthesizing non-utilizable sterols. These plants grow and develop normally. Cotton bollworm, mirid and diamondback moth reared on the modified Arabidopsis plants have delayed growth and decreased survival rate. Subsequently, the transformation of these genes into canola has been achieved. The canola plants containing modified sterols are being tested for resistance to Redlegged earth mite, Diamond back moth, Aphids and nematodes.

This novel technology has potential to be applied to a wider range of grain crops to control leaf chewing, sap-sucking and root insect herbivores.

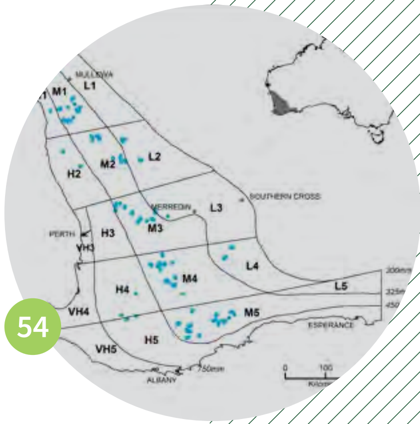
52: Modification of plant sterol composition for insect resistance.

53: Tests on transgenic canola for Redlegged earth mite resistance.

The role of biophysical constraints as drivers of land use change in the farming systems of south-west Western Australia

Project team: Martin Harries[1,2] (project leader; martin.harries@dpird.wa.gov.au), Associate Professor Ken Flower[1], Dr Michael Renton[1], Dr Craig Scanlan[1,2]

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



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Agricultural land use patterns have changed substantially within south-west Western Australia in the past few decades. Between 2000 and 2015, the area per farm dedicated to pasture declined by up to 30 per cent in some agro-ecological zones of south-west WA and sheep numbers declined from 26 to 14 million head. The area sown to wheat, barley and canola increased by 0.7, 0.3 and 0.7 million hectares respectively, while legume crop area declined by 0.6 million hectares for lupin and 0.13 million hectares for pulses combined. This has resulted in substantial changes to rotations. These changes in land use and associated farming practices induce complex changes in the agro-ecological environment, which require periodic reassessment.

We are using survey data comprising of biophysical measurements and farm management records from 2010 to 2015 across 184 fields in south-west WA to assess if recent changes in agricultural land use patterns and associated agricultural practices are causing detrimental changes to key biophysical variables.

Our first paper, titled “Interactions between crop sequences, weed populations and herbicide use in WA broad acre farms: findings of a six-year survey” highlighted that farmers are successfully controlling herbicide resistant weeds, with weed numbers in monitored crops at low densities.

However, there was a heavy reliance on glyphosate, and in order to minimise the weed seed bank within crops, pastures were used infrequently in some regions and in 50 per cent of cases pastures were actively managed to reduce weed seed set, by applying a non-selective herbicide in spring. The use of non-selective herbicides in this manner also kills pasture plants, consequently self-regenerating pastures were sparse and contained few legumes where cropping intensity was high.

Overall, the study indicated that land use selection and utilisation of associated weed management actions were being used successfully to control weeds within the survey area. However, to successfully manage herbicide resistant weeds land use has become less diverse, with pastures utilised less and crops with efficacious weed control options utilised more.

We are continuing this research by assessing the impacts of these changes in land use on other production factors, including assessments of soil nutrient management and plant pathogens from the same dataset, to assess sustainability of these weed management practices in a wider context.

This research is supported by DPIRD.

54: Locations of the paddocks monitored within the study.

55: PhD candidate Martin Harries at field trials near Wongan Hills.


Northern cattle in Western Australia.
Photo: Dean Revell

2

Sustainable Grazing Systems

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Research undertaken in the Sustainable Grazing 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 (RDE&A) partners.

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

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

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

An analysis of the impacts of oestrogenic subterranean clover on the reproductive and thermoregulatory function of Merino sheep in south-western Australia

Project team: Mia Kontoolas[1], Dr Dominique Blache[1], Professor Megan Ryan[1] (project leader; megan.ryan@uwa.edu.au), Dr Kevin Foster[1], Dr Caitlin Wyrwoll[1], Tim Watts[1], Dr Kelsey Pool[1]

Collaborating organisation: [1]UWA; DPIRD

The negative impacts of grazing oestrogenic sub clover on ewe reproduction, termed Clover Disease, was identified in the 1970s and 1980s. Phytoestrogens are gaining in popularity as a research topic due to their impact on livestock and potential implications for human health. However, the mechanisms by which ingestion of phytoestrogens affect the reproductive system is still poorly understood. Mia Kontoolas' PhD project aims to improve our knowledge of these mechanisms and identify why some ewes can still reproduce while grazing oestrogenic sub clover.

In 2020, Ms Kontoolas investigated the molecular basis of both infertility and resistance in ewes exposed to oestrogenic clover by studying the impact of long-term exposure (five to six years) on the oestrogen receptor cellular mechanisms and morphology of the ewe reproductive tract. Histological staining and microscopy examination has been used to determine the precise effects of phytoestrogen exposure on the morphology and histology of the ewe reproductive tract.

Ms Kontoolas' future work will include extensive field trials examining ewes in different stages of the reproductive life cycle – from fetal and early neonatal life to pregnancy – for responses to oestrogenic sub clover. The research will include detailed pasture analysis to determine oestrogenic dosage and response of ewe fertility to seasonal sub clover biochemical variations.

The ultimate goal is to impact the agricultural industry in the following ways:

- Increase the number of live lambs produced per ewe mated
- Increase the survival rate of lambs in the critical periods of gestation and early life, minimising reproductive wastage
- Increase the reproductive lifespan of ewes by preventing loss through dystocia and prolapse, thus reducing adult flock losses
- Provide greater clarity around the molecular mechanisms contributing to stillbirth, uterine prolapse, dystocia and failure to conceive, which will help elucidate non-phytoestrogen causes of ewe infertility
- Reduce or eliminate potential animal welfare concerns before they become medical issues
- Contribute to future diagnostic tools for Clover Disease, allowing producers to quickly and cheaply assess clover infertility issues
- Increase education, understanding and provide outreach to producers regarding oestrogenic clover risks and Clover Disease, and
- Improve producer confidence in their choice of pasture legumes and management

This research is supported by the UWA Lefroy Family Bequest, MLA Postgraduate Research Scholarship and UWA Calenup Postgraduate Research Scholarship.

1: Mia Kontoolas monitoring ewe health during an experiment on a farm in south-west of Western Australia.

2: High-resolution (40x) image of uterus of a ewe exposed to dietary phytoestrogens via oestrogenic sub clover. Sample has been stained with a Masson's trichrome protocol, which renders collagen blue, muscle red and cell nuclei black.

Can *Khaya senegalensis* improve gut health in sheep?

Project team: Suyog Subedi[1] (project leader; suyog.subedi@research.uwa.edu.au), Emeritus Professor Graeme Martin[1], Professor Philip Vercoe[1], Dr Zoey Durmic[1], Stephanie Payne[1], Associate Professor Andrew Richard Williams[2]

Collaborating organisations: [1]UWA; [2]University of Copenhagen, Denmark; CSIRO; DPIRD; Bioactive Laboratories

This research, as part of Suyog Subedi's PhD project, aims to isolate and identify natural compounds from the African Mahogany tree to test if it can improve gut health in livestock. During 2019, we isolated certain fraction from the bark and leaf of the tree and to some extend proved that they are bioactive. However, for a more confirmatory result we required fresh parasite larvae, which we were struggling to source. We then collaborated with the University of Copenhagen and decided to perform the test at their lab.

In 2020, Mr Subedi flew to the University of Copenhagen to test the fractions he previously extracted. As he was about to begin work in Denmark, the COVID-19 pandemic hit and the lab closed. Then, Australia closed its border and he was stranded offshore for nine months. As a result, he could not achieve all the annual milestones, but learned a new parasitological bioassay technique and is now working on setting it up at UWA. He was also able to prove that few fractions from the bark and leaf of the test plant has a strong anti-parasitic property.

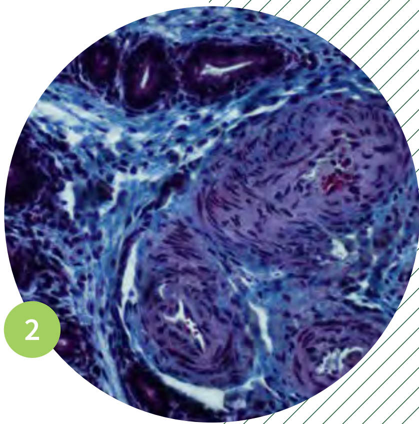
This result backs the research hypothesis and gives us a platform to focus toward identifying and isolating the group of compound responsible for the bioactivity. Moving on to 2021, we hope to identify the compound/compounds and prove that they improve gut health in livestock.

This research is supported by UWA and the Mike Carroll Travelling Fellowship.

3: Larval mortality assay.

4: Larvae under magnification.

1



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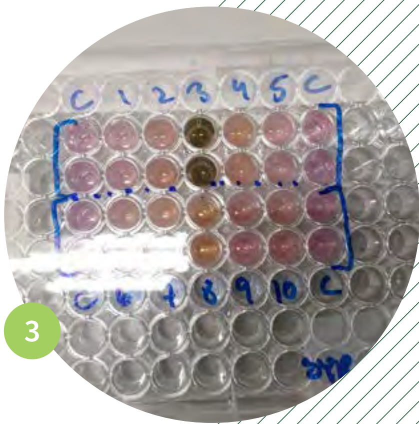

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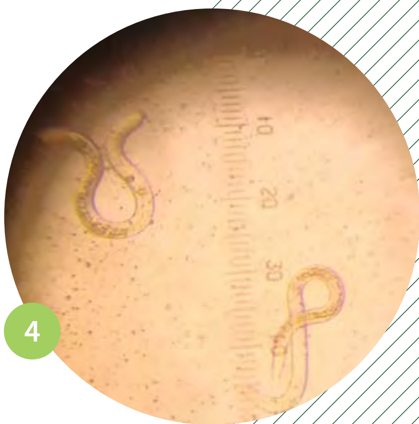

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5

Feeding sheep with cactus

Project team: Dr Cesar Rosales Nieto[1] (project leader; cesar.rosales@uaslp.mx), Dr Venancio Cuevas-Reyes[2], Dr César Meza-Herrera[3], Dr Morteza Ghaffari[4], Dr Antonio Gonzalez-Bulnes[5], Dr Francisco Santiago-Hernández[6], Dr Jorge Urrutia-Morales[6], Dr Manuel Flores-Najera[6], Dr Alfonso Chay-Canul[7], Dr Maribel Rodríguez-Aguilar[8], Dr Juan Vázquez-García[8], Emeritus Professor Graeme Martin[9]

Collaborating organisations: [1]Universidad Autónoma de San Luis Potosí México; [2]Agrícolas y Pecuarias, Texcoco, México; [3]Universidad Autónoma Chapingo, México; [4]University of Bonn, Germany; [5]Departamento de Reproducción Animal INIA, Spain; [6]Instituto Nacional de Investigaciones Forestales – Agrícolas y Pecuarias, México; [7]Universidad Juárez Autónoma de Tabasco, México; [8]Universidad Autónoma de San Luis Potosí, México; [9]UWA

Small ruminants are often the principal economic activity in arid and semiarid regions, where production systems depend solely on the forage resources from usually degraded rangelands. The animals are rarely fed nutritional supplements because high-quality pastures and concentrates are not readily available and usually too expensive. An alternative source of forage is the *Opuntia* genus, a family of cacti that are abundant and produce cladodes (leaves) that are highly digestible and can provide significant amounts of water and energy. The potential of *Opuntia* surfaced in Tunisia in 2012 when Dr Mourad Rekik described the 'cactus effect' as an alternative to the 'lupin effect' that we commonly use in Australia. Here, we test this idea further in Mexico.

In our first study, using sheep supplemented during late gestation, we compared lucerne with cladodes of *Opuntia ficus-indica*. Birth weight was not affected, but progeny born to Opuntia-fed ewes grew faster and were heavier at weaning, despite the fact that Control ewes produced more milk.

In our second study, we assessed urinary metabolomic profiles. For 76 metabolites, there were major differences between the lucerne and *Opuntia* supplements, suggesting that *Opuntia* induced major changes in the metabolism of glucose, tyrosine, methane, and glycerolipids. These effects were related to improvements in fertility and reproductive rate in the *Opuntia*-fed ewes.

It seems that the responses to *Opuntia* supplements do not simply reflect the effects of good nutrition (i.e. more energy and protein) but are caused by specific metabolites/metabolomic pathways. We need further research into the mechanisms through which *Opuntia* supplements affect the reproductive system but, meanwhile, it seems likely that feeding *Opuntia* cladodes can reduce production costs in ewes managed under extensive conditions in arid and semiarid regions.

This research is supported by the National Institute for Research in Forestry, Agriculture and Livestock in Mexico (INIFAP).

5: Rambouillet sheep (Merino) consuming cladodes of the *Opuntia* cactus.

Molecular analysis of the gut of sheep genetically selected for helminth resistance

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

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

The sheep industry is an important contributor to the Australian economy because sheep meat and wool are consumed domestically and exported to many parts of the world. A major challenge faced by the industry is diseases caused by bacteria, viruses, fungi and gastro-intestinal helminths, leading to huge economic losses. In the winter rainfall zones of WA, Merino sheep suffer from diarrhoea caused by parasitic gastro-intestinal worms, the 'helminths', especially *Teladorsagia circumcinta* and *Trichostrongylus colubriformis*.

Since the 1990s, Dr Johan Greeff and his colleagues have been breeding sheep for resistance to these helminths and they have produced the 'Rylington Merino' flock, the most helminth-resistant sheep in the world. However, among the resistant animals, exposure to even a few helminths leads to severe diarrhoea in some animals.

We are investigating this problem at gene level, using transcriptomics, to compare sheep that are a) resistant to infection with no diarrhoea; b) sheep that are resistant but still develop diarrhoea; and c) sheep that are fully susceptible to helminth infection. We then extract RNA, sequence it, and analyse the data using the Pawsey Supercomputer and bioinformatics software.

The first part of project focuses on analysis of gene expression of two parts of small intestine, namely the duodenum and Ileum. Analysis of duodenum, the site of infection, shows that sheep that resist diarrhoea have switched on important genes that control the way the immune system responds to worm infection. By contrast, sheep that are highly susceptible to diarrhoea have switched on genes that control biological processes and pathways related to tissue repair as they attempt to resist damage to the tissues of the digestive tract.

The Ileum has never been studied for its role in parasitic diarrhoea because it is not a site for helminth infection. However, our histology observations led us to test whether an analysis of gene expression could shed light on mechanisms responsible for diarrhoea. The analysis of these data is ongoing.

To better understand host-parasite interaction, it is important to understand the fundamentals of helminth parasite biology and in this pursuit we now have a new tool, 'genome assembly', that allows insight into the biology of any organism of interest. Therefore, in the next part of the project, PhD student Shamshad Ul-Hassan is aiming to improve the draft genome assembly of *Teladorsagia circumcinta* by completing it at chromosome length. He is using the chromosome conformation capture technique to capture parts of chromatin that are in close proximity to each other. The sequencing has been done and he is now combining the sequences with the draft genome.

By understanding the interactions between the sheep and helminth genomes, Mr Ul-Hussan hopes to offer industry a pathway towards a genetic solution to the helminth problem.

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

6: Dr Erwin Paz and Shamshad Ul-Hassan working in the laboratory at the UWA Marshall Centre.

Optimisation of production efficiencies and practical limits to the methane intensity of sheepmeat

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; [2]CSIRO Agriculture and Food

Greenhouse gas emissions associated with WA's sheep flock accounts for approximately 26 per cent of the state's agricultural emissions, principally (96 per cent) as a result of methane (CH4) emitted by the animal via enteric fermentation.

A 44 per cent drop in sheep numbers in WA from 2005 to 2019 was reported as a corresponding decrease in emissions under the Australian Government's national greenhouse gas inventory. However, this methodology does not facilitate an evaluation of potential changes in the methane intensity of sheepmeat (Kg product/Kg CO2 e-).

With current sheepmeat commodity prices being high, a modest rebuild of sheep numbers is forecast by 2030. Unless this increase in numbers is matched with concurrent improvements in methane intensity, emissions associated with the state's sheep flock will rise.

Through a meta-analysis of animal based parameters that contribute to the methane intensity of sheepmeat, we evaluated changes in methane intensity from 2005-2019. Through the CSIRO's whole farm modelling software (GrassGro V3), we then evaluated a series of future scenarios against a 2030 horizon and against practical limits under current production systems.

This research is supported by UWA.

7: Sheep at UWA Farm Ridgefield.

Ovulation and ovulation rate in ewes under grazing conditions: factors affecting the response to short-term supplementation

Project team: Dr Georgget Banchero Hunzicker[1,2] (project leader; gbanchero@inia.org.uy), Dr Katia Stefanova[1], Emeritus Professor David Lindsay[1], Graciela Quintans[2], Fernando Baldi[3], Dr John Milton[1], Emeritus Professor Graeme Martin[1]

Collaborating organisations: [1]UWA; [2]INIA La Estanzuela, Uruguay; [3]São Paulo State University

The relationships between ovulation rate and nutrition remain confused, probably because of uncontrolled variation in experimental conditions. To help resolve the problem, we analysed data from 20 experiments conducted between 2002 and 2016 in Uruguay with grazing ewes. All experiments were carried out by a single laboratory under comparable conditions of experimental design and measured variables. The studies used a total of 3,720 ewes, of purebred Corriedale, Polwarth, or East Friesian x Polwarth genotypes. In all experiments, a control group grazed native pastures and extra nutrition was provided to the treatment groups using either improved pastures or supplements.

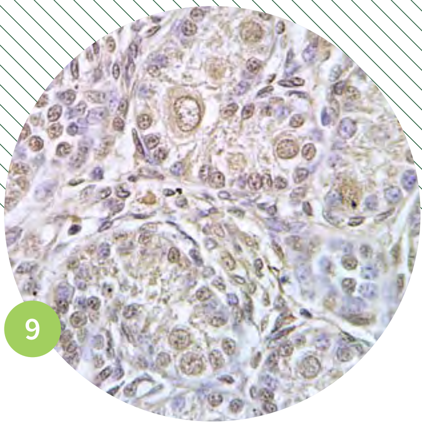
Ovulation rate was measured by counting corpora lutea using laparoscopy or rectal ultrasound or by counting fetuses at ultrasound on day 45 of gestation. For statistical analysis, data were grouped according to nutritional treatment (control or supplemented) and, within these groups, type of supplement to provide energy or protein (protected or not from rumen degradation). Across all experiments, 92–99 per cent of the ewes ovulated and the effects of diet, length of supplementation, and initial live weight and genotype are reported. Within diets, ovulation was most affected by overall energy intake during supplementation ($P < 0.01$). Ewes that grazed native pastures supplemented with protein supplements had higher ovulation rates ($P < 0.05$) than control ewes grazing only native pastures. The addition of tannins to the protein supplement, to protect it from degradation in the rumen, did not further increase the ovulation rate.

In unsupplemented ewes that had access to legume pastures, ovulation rates did not increase when the legume pasture was rich in tannins although only ewes that grazed tanniniferous legumes had marginally higher ovulation rates than the control ewes ($P < 0.05$). When ewes grazing native pastures were supplemented with energy, their ovulation rate did not increase above those of nonsupplemented ewes. Live weight at the start of supplementation also affected ovulation rate.

This research showed that, in general, the decision to ovulate was most affected by overall energy intake. The factors that affected ovulation rate during short-term nutritional supplementation were intake of protein from highly digested supplements or dietary protein protected from ruminal degradation.

This research is supported by UWA and INIA, Uruguay.

8: Dr Georgget Banchero and Dr Graciela Quintans visiting UWA Farm Ridgefield.



Pregnant ewes that are underfed or heat-stressed will probably produce low-fertility ram lambs

Project team: Graciela Pedrana[1] (project leader; gpedrana@gmail.com), Daniel Cavestany[1], Paula Lombide[1], Helen Viotti[1], Dr Deborah Sloboda[2], Emeritus Professor Graeme Martin[3]

Collaborating organisations: [1]Universidad de la República, Uruguay; [2]McMaster University, Canada; [3]UWA

Pioneering studies of health history by DJP Barker gave rise to the concept that undernutrition and stress in the pregnant woman will affect the development of the fetus and predispose her children to chronic diseases in later life. The Barker Hypothesis is now commonly referred to as the 'Developmental Origins of Health and Disease' and has been extended to farm animals. For example, undernutrition of the ewe during the prenatal and early post-natal life of her ram and ewe lambs leads to poor development of the reproductive system. This phenomenon could explain much of the between-animal variation in twinning and sperm production that typifies sheep flocks on farm.

In addition to undernutrition, we would expect stress in the mother to affect the developing fetus because stress increases the blood concentrations of the adrenal hormone, glucocorticoid. Research in this area has also been driven by medical research for humans. Glucocorticoid is given to mothers expecting a premature baby to mature the baby's lungs, a treatment that probably saves 600 thousand babies every year. The original discovery was made using sheep in New Zealand by Mont Liggins and medical researchers all around the world (including teams at UWA), still use the pregnant sheep as an experimental model to explore and fine-tune the treatment.

The UWA medical researchers have also collaborated with animal scientists in the search for unwanted side-effects of the glucocorticoid therapy. A long-lasting link between UWA, Uruguay and Canada has shown that, in the testis of the ram fetus, prenatal glucocorticoid affects:

- Glucocorticoid receptors
- An enzyme involved in the synthesis of testosterone)
- The production of proteins involved in apoptosis ('cell suicide'), and
- The production of heat shock protein 70 (HSP70), a factor that mediates responses to heat stress.

Overall, it seems likely that stress in the pregnant ewe will affect the proliferation and differentiation of testis cells in the developing ram lamb, and perhaps the ability of the young ram to avoid the effects of heat stress on fertility.

Additional research is required to find the consequences for fertility in mature rams on a flock scale under farm conditions.

This research is supported by the Universidad de la República in Uruguay, CSIC and CIDEC.

9: Cross-section of fetal ram lamb testis after prenatal treatment with glucocorticoid. Brown colouration shows the presence of glucocorticoid receptor. We can see the sex cords (one is outlined with a broken line) that will become seminiferous tubules, the site of sperm production in the adult. The sex cords contain sperm progenitors (gonocytes) in which there is brown staining of the cytoplasm (an example is indicated with a black arrow) and the nucleus (such as the one indicated by the broken arrow).

This means that glucocorticoids can bind to DNA and change cell activity. Sertoli cells that will nurse the developing sperm later in life are seen near the membrane that envelopes the sex cords, and they also have a brown nucleus (red arrow). Finally, myoid (muscle-type) peritubular cells (blue arrow) also stained.

10

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), Dr Dominique Blache[1], Professor Megan Ryan[1], Dr Kevin Foster[1], Dr Caitlin Wryroll[1], Mia Kontoolas[1], Dr Jeremy Smith[1], Professor Philip Vercoe[1], Emeritus Professor Graeme Martin[1], Tim Watts[1], Daniel Kidd[1]

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

In sheep, intake of oestrogenic pastures is shown to severely compromise reproductive function in the ewe and represents an ongoing hindrance 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 2020, funded by the Lefroy Family Bequest for research in Merino sheep, we further investigated clover disease in both the ram and ewe, and began developing methods for prognostic detection of compromised reproduction. In the ram, our research shows that the phyto-oestrogens associated with clover disease detrimentally impact sperm function, reducing fertilising potential. We have had the opportunity to convey some of this information to producers and industry partners in WA during conferences in Southern WA. Further confirmation of these findings in the ram will be used to inform upon policies and recommendations concerning the grazing of livestock on oestrogenic pastures.

Our work concerning phytoestrogen exposure in the ewe saw the establishment of a collaboration between UWA and Curtin University. Our preliminary work, using chemical imaging technology at Curtin University was used to detect biomarkers of clover disease in the ewe, which will ideally contribute to a prognostic management option for flocks affected by oestrogenic pasture as well as informing on the mechanisms driving pathological change.

The information from both of these studies is likely to alter current recommendations surrounding the management of livestock on oestrogenic pasture in Australia.

This research is supported by the UWA Lefroy Family Bequest and MLA.

10: UWA Lefroy research fellow Dr Kelsey Pool checking the outcomes of a previous artificial insemination trial in sheep.

Maximising the reproductive potential of the meat sheep industry by eliminating high oestrogen clovers, more live lambs on the ground

Project team: Dr Kevin Foster[1](project leader; kevin.foster@uwa.edu.au), Daniel Kidd[1], Professor Megan Ryan[1], Dr Dominique Blache[1], Emeritus Professor Graeme Martin[1], Professor Philip Vercoe[1], Associate Professor Caitlin Wyroll[1], Dr Zoey Durmic[1], Mia Kontoolas[1], Dr Jeremy Smith[1], Tim Watts[1], Dr Kelsey Pool[1]

Collaborating organisations: [1]UWA; MLA Donor Company; DPIRD

Subterranean clover is the dominant annual pasture legume in southern Australia (30 M ha) and is an essential part of the livestock industry. Reproductive difficulties in sheep grazing subterranean clover pastures high in oestrogenic compounds were first described in the 1940s. Oestrogenic subterranean clovers can cause two forms of infertility:

- Short term; characterised by suppression of oestrus with a return of fertility after removal from the oestrogenic pastures, and
- Permanent infertility that increases in severity with continued exposure.

In 2020, we engaged with 230 producers, vets and consultant via three Zoom meetings and 60 producers and industry representatives via a field day in WA. These zoom seminars, field days and lectures have led to a much greater awareness among producers, agronomists and veterinarians of the impact of high oestrogenic clovers. During the growing season, we also disseminated 78 free pasture kits across southern Australia with clover ID sheets to producers with a return rate of 70 per cent. Many of the kits returned contained several paddock samples from farms in the one kit. We found many of the samples returned contained at least one sample above the current designated safe level of formononetin. Our survey also asked if producers thought they had an oestrogenic problem, and 70 per cent of respondents said they believed they did or were unsure.

Many of the samples of subterranean clover we have surveyed also showed deficiencies of phosphorus and sulphur, both of which increase pasture oestrogenicity when growth is limited.

We continue to train undergraduate students in oestrogenic clover identification at UWA and Curtin University and provide on-going supervision of Honours, Masters and PhD students undertaking plant and animal studies on oestrogenic clover. The project team has increased in 2020 and will continue to work together to gather essential information to help shape our thinking on the oestrogenic issues addressed by the project. Dr Kelsey Pool has recently been appointed as Research Associate under the Lefroy fellowship to examine the effects of oestrogens on the ram. Mia Kontoolas is undertaking her PhD on the impacts of oestrogenic subterranean clover on the reproductive function of Merino sheep in south-western Australia.

We now also have an international collaboration and five-year project with three universities in North America and the United States Department of Agriculture on the effects on phytoestrogens on livestock. UWA is still the clear world leader in this area of phytoestrogens and livestock research.

The abattoir and on-farm studies research will continue at UWA. It is already the largest investigation into oestrogenic subterranean clover ever undertaken in southern Australia. By its completion, it will redefine the whole issue of oestrogenic clover and its impacts on livestock not only for the ewe, but also the ram and lamb.

This research is supported by the Lefroy Family Bequest and MLA Donor Company.

11: UWA Lefroy Fellow Dr Kelsey Pool presenting at the Western Beef field day.

12: Mia Kontoolas presenting her PhD project via Zoom on oestrogenic clover at Australian Grasslands Association virtual conference.

13

The serotonin pathway, temperament, and adaptation in Merino sheep

Project team: Dr Dominique Blache[1] (project leader; dominique.blache@uwa.edu.au), Professor Shane Maloney[1], Luoyang Ding[1], Yuri Kitagawa[1,2]

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

In humans and laboratory rodents, serotonin (5-HT), a neurotransmitter that is widely distributed in the mammalian brain, has important roles in temperament related behaviours like anxiety, happiness, psychosis, aggressiveness, and low social affiliation. It is also involved in the homeostatic control of energy intake and body temperature. Recently, we have identified an association between a single nucleotide polymorphism (SNP) in the serotoninergic pathway and the temperament phenotype of sheep. The SNP is located in the gene that codes for the enzyme that is responsible for the production of serotonin (Tryptophan hydroxylase: TPH2 gene). The sheep carrying genotype CC in the TPH2 gene are calmer than the sheep carrying genotype TT. A question remains; can the association between the SNPs and temperament be attributed to a difference in the functionality of the serotoninergic pathway? This project aims to answer this question.

This research aims to compare the differences in temperament, other associated genomic variations, body temperature, and other stress related biochemical factors in sheep carrying the different genotypes on the TPH2.

In the past 12 months, blood was sampled from 150 sheep with similar body weight from a flock with 200 sheep. Those samples were used to genotype the animals according to the two SNP variants in the gene for tryptophan hydroxylase. We selected three groups of nine sheep with either CC, TT, or CT at the SNP location. The sheep were implanted with temperature loggers, and we tested their temperament phenotype using two behavioural tests (the arena test and the isolation box test) twice, two-week's apart. Blood was collected after each behavioural test. The temperature loggers were recovered at the end of the experiment in December 2020. The blood samples were analysed for indicators of stress, such as cortisol and thiol oxidation.

The sheep that carry genotype CC had significantly lower scores in the isolation box test than the other sheep; although no differences in the number of Bleats or the number of Crosses were identified between the groups in the arena test. All of the sheep had higher thiol oxidation after the behavioural tests, but there was no difference in thiol oxidation between sheep of different genotypes for TPH2. The blood samples are now being analysed for miRNA and paraspeckle expression as well as associated SNPs.

This research is supported by the UWA-Nagoya Joint PhD Scholarship.

13: Sheep in a race waiting to be sampled for genotyping for trytophan hydroxylase.

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17

The relationship between ultradian rhythms of body temperature and biological status in livestock

Project team: Dr Dominique Blache[1] (project leader; dominique.blache@uwa.edu.au), Yuri Kitagawa[1,2], Professor Shane Maloney[1], Luoyang Ding[1], Professor Satoshi Ohkura[2]

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

Animals adapt to changing environments by evolving biological systems that are as energetically efficient as possible. In homeothermic animals (including livestock), core body temperature is tightly controlled by thermoregulatory homeostasis. Recently, it has been suggested that variation in the core body temperature could reflect the fitness of an animal. Variations in the circadian rhythm of body temperature can occur in response to environmental stimuli, but the drivers remain unknown. This project aims to explore the relationship between variation of the daily rhythm of core body temperature and the biological status of the animal to identify the drivers of that variation. This project is conducted in collaboration with Nagoya University in Japan.

In 2020, we implanted temperature data loggers in goats at Nagoya University farm and sheep at UWA Farm Ridgefield. All of the temperature loggers measured core body temperature every five minutes for several months.

At Nagoya University, the goats were exposed to several challenges including a decrease in energy intake and movement restriction. The daily amplitude of core body temperature correlated significantly with ambient temperature, while energy intake and restraint on movement had variable effects on the circadian rhythm.

At UWA, we selected sheep with SNPs that affect temperament and conducted behaviour testing (arena test and isolation box test) twice to measure the impact of psychological stress on core body temperature and its rhythms. The sheep that carry a nervous genotype had a larger stress induced hyperthermia during the behavioural testing than the sheep carrying the calm genotype. The daily amplitude of core body temperature was also affected by the genotype for TPH2.

The large data sets obtained from goats and sheep are still under analysis. Our results suggest that the daily amplitude of core body temperature is affected by a large array of factors, including ambient temperature and psychological stress, and therefore could be a reliable indicator of stress.

This research is supported by JSPS and the UWA-Nagoya Joint PhD Scholarship.

14: Goats used in the experiment conducted at Nagoya University, Japan.

Optimal sheep stocking rates for broadacre farm businesses in Western Australia

Project team: Michael Young[1], Professor Philip Vercoe[1] (project leader; philip.vercoe@uwa.edu.au), Professor Ross Kingwell[1]

Collaborating organisations: [1]UWA; DPIRD

Sheep stocking rate influences farm profit significantly. However, determining the optimal stocking rate can be difficult, particularly when climatic conditions are uncertain. Optimising stocking rate requires an understanding of the quantity and quality of feed available throughout the year, the optimal live weight profile throughout the year, the impact of seasonal variation, the impact of labour availability, the cost of alternative feeds, prices of livestock and livestock products, and the risk preferences of the farmer. To evaluate the stocking rate that maximises whole-farm profit thus requires detailed whole farm optimisation modelling.

To efficiently and accurately optimise large problems, such as a farm system, linear programming is widely used. There are two main linear programming frameworks; stochastic, and deterministic. Additionally, there are various ways to represent a farm system within each framework. However most modelling applications employ a single modelling structure. Thus, there is little understanding of how best to model farm systems.

The aims of this research are to:

- Develop a new farm optimisation model utilising successful concepts from existing farm models including MIDAS and MUDAS. The nature of the model must incorporate seasonal variation, price variation, farmers' tactical choices in managing livestock and cropping enterprises, and a farmer's risk attitude. Furthermore, the model must include the ability to easily change between different modelling frameworks
- Apply the model to examine how management of a farming system alters when different modelling frameworks are applied, and
- Apply the model to evaluate the optimal stocking rate for farms in the southwest of the Western Australian wheatbelt.

The primary activity for 2020 was model development and documentation. Version 1 of the deterministic section of the model has been developed and largely documented. Additionally, a review paper on sheep stocking rate has been completed and will shortly be submitted to Animal Production journal.

2021 will hold further model development and documentation, specifically the addition of the stochastic framework.

This research is supported by Sheep Industry Business Innovation (DPIRD).

15: PhD student Michael Young.

BeefLinks Partnership Program

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

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

The BeefLinks Partnership Program has now been underway for a year. It is a collaborative research, development, extension and adoption (RDE&A) partnership involving MLA, MLA Donor Company and UWA. 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 programme 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. The project is really at an exciting time because we now have five contracted projects, including:

- BeefLinks Coordination Project
- Growing WA backgrounding through adoption
- 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, and
- BeefLinks: Management of cattle in the Australian rangelands using virtual fencing/herding technologies.

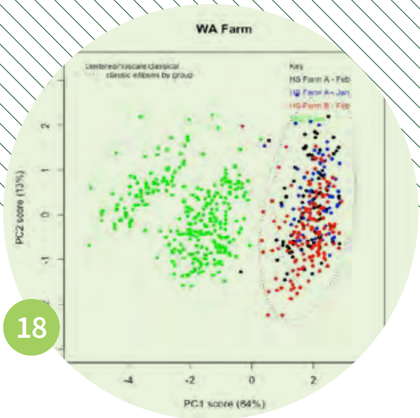
We are also involved in an MLA Producer Demonstration Site developed with the Gascoyne Catchment Group – 'Pastoral Partners Accelerating the Transition', which links closely with the backgrounding project. There will be other projects coming online in 2021, including a socio-economic project to help 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 MLA Donor Company.

16: Cattle at Hamersley Station.

17: BeefLinks team members Leah Sackville, Peter Hutton, Bruce Manyard, Sean D'Arcy and Cath Walsh at Lyndon Station.



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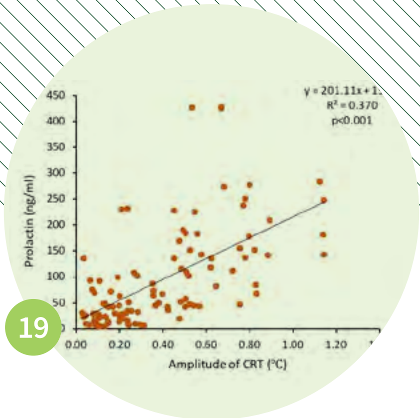

19

20

Detection and mitigation of the impact of heat stress on the productivity of Australian dairy cattle

Project team: Dr Dominique Blache[1] (project leader; dominique.blache@uwa.edu.au), Professor Shane Maloney[1], Dr David Walker[1], Dr Hayley Norman[2], Dr Leah Marett[3], Shilja Shaji[1]

Collaborating organisations: [1]UWA; [2]CSIRO; [3]DEDJTR Victoria

Climate change will impact dairy animals both directly and indirectly. An increase in the severity and frequency of heat stress is an obvious direct impact, which creates serious economic losses to dairy farmers. Heat stress in dairy cattle is assessed using an index calculated from the ambient temperature and humidity. The response to heat stress varies with the duration and the amplitude of the heat wave, the individual resilience to heat stress, and the circadian regulation of bodily functions including thermoregulation. None of these factors are considered when predicting heat stress responses in dairy cattle.

This project has three aims:

1. Development of a simple and reliable technique to detect heat stress in lactating dairy cattle from milk samples. We investigated the ability of Near Infrared Reflectance Spectroscopy (NIRS) to detect heat stress in individual dairy cattle from milk samples. Using a principal component analysis (PCA), the NIRS can differentiate between milk collected from heat stressed cattle and non-heat stressed cattle. However, the scores from the PCA analysis were not correlated with any of the known classic heat stress parameters in milk.
2. The circadian rhythm of core body temperature, milk production, and hormonal responses in lactating dairy cattle during heat stress. The circadian rhythm of body temperature, production data, and hormone data were analysed from the three experiments conducted in climate chambers at DEDJTR in Ellinbank, Victoria. The amplitude and maximum of the daily rhythm of body temperature were better indicators of heat stress than the average. Prolactin was found to be a better heat stress marker than cortisol. The amplitude of the daily rhythm of body temperature was correlated with the serum prolactin (R2 =0.37, and P<0.001).
3. To measure the individual variability in milk production of lactating dairy cattle during heat stress. Using 10 years of herd testing data (approximately 1.6 million data points) along with weather data collected from the Bureau of Meteorology close to each farm, we are in the last stages of developing a model using Bayesian methods to investigate the impact of the timing, duration, and amplitude of heat waves on milk production.

This research is supported by the Faculty Scholarship for International Research Fees, The Edward Moss PhD Scholarship, Tim Healey Memorial Scholarship PhD Top-up Stipend, Elizabeth Clark Top-up Scholarship and Western Dairy Research Scholarship.

18: Plots of principal component scores for milk samples collected from three different WA farms under normal and hot weather conditions. The green dots (TNZ Farm) represent milk samples collected during benign weather conditions. The black, blue, and red dots represent milk samples collected on hot days.

19: Linear relationship ($p<0.001$) between the amplitude of the daily rhythm of body temperature (°C) and serum prolactin concentration (ng/ml) for data collected during a climate chamber experiment at DEDJTR, Victoria.

Fit for purpose biochar to improve efficiency in ruminants

Project team: Dr Martinez Fernandez Gonzalo[1], Professor Philip Vercoe[2] (project leader; philip.vercoe@uwa.edu.au), Dr Zoey Durmic[1], Dr Joy Vadhanabhyuti[2], Dr Lucas Smith[2], Dr Rob Kinley[2], Dr Stephen Joseph[3], Dr Sarasadat Taherymoosavi[3]

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

Biochar is product derived by pyrolysis of waste biomass, usually used as soil improver, but can be fed to the animal to reduce enteric methane emissions and improve feed efficiency. To date, biochar fed to the animals were those developed for other applications, but they can be made fit-for-purpose by manipulating the production process. In this project, we manipulated the biochar process to produce fit-for-purpose biochar for ruminants. In 2019, we developed and tested a range of biochars, picking the most active and promising ones. From these, we developed 'Next Generation biochars' (Next Gen BC).

In 2020, we conducted experiments to validate these NextGen BC in an open, continuous in vitro system ('artificial rumen') and then quantified and validated their effects in cattle, in an animal house experiment. We concluded that the biochars can be manipulated to target enteric methane emissions and improve feed efficiency in cattle. In 2021, the plan is to validate these findings further in grazing trials in both QLD and WA.

This research is supported by MLA.

20: Biochar about to be fed to the animal.

21: Biochars being tested in 'artificial rumen'.

Annual Legume Breeding Australia (ALBA)

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

Collaborating organisations: [1]UWA; PGG Wrightson Seeds

Annual Legume Breeding Australia (ALBA) is a joint venture between UWA and the pasture seed company 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 (*Trifolium subterraneum*), balansa clover (*T. michelianum*), Persian clover (*T. resupinatum*) and arrowleaf clover (*T. vesiculosum*).

Breeding highlights included the continuation of Stage 2 trials in WA, Victoria, New South Wales and New Zealand of advanced breeding lines of subspecies *subterraneum* and *yanninicum* subterranean clover for high rainfall areas and further selections among Persian and arrowleaf clover breeding populations. Selection of subterranean clover breeding lines for low and medium rainfall areas also continued at the UWA Shenton Park Field Station and at Boyup Brook. Evaluation of balansa clover accessions was conducted at Shenton Park to identify potential parents for crossing.

In 2020, PhD student Gereltsetseg Enkhbat examined diversity within the Australian collection of ssp. *yanninicum* subterranean clovers for waterlogging tolerance. These were also screened for seedling resistance to red-legged earth mites and underwent preliminary evaluation and seed increase at Shenton Park. The aim is to identify parents to introduce new traits and expand the genetic base of ssp. *yanninicum* subterranean clovers.

This research is supported by PGG Wrightson Seeds (Australia) Pty Ltd.

22: Transplanting germinated clover seeds from Petri dishes into the glasshouse - with social distancing. They are transplanted to the field six weeks after sowing.

23: Subterranean clover and balansa clover breeding plots at Shenton Park.

Bee Friendly Pastures: New opportunities for premium honey production

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

Collaborating organisations: [1]UWA; Bell Pasture Seeds; Elgin Western Australia; AgriFutures Australia

Historically, Australia has been self-sufficient with native flora nectar and pollen supply for its bees. The floral resources available to the apiculture industry in Australia are threatened by land clearing, restricted access to public lands, pest and disease pressure and the effects of a warm climate such as drought and bushfire. However, an exciting new project has begun at UWA, to assess annual and perennial pasture legumes for suitability to provide alternative forage resources for honey bees.

Annual and perennial nitrogen-fixing legume species are important animal forages across the world. Many of the Trifolium species of Mediterranean origins are adapted to dry areas, yet produce copious nectar and, when foraged by a bee, produce honeys with distinct complex flavour profiles. These species often grow wild and are highly valued for their honey production overseas. Some species are already in commercial production in Australia, with others soon to be released. However, few are currently grown or being assessed specifically for honey production.

Critically, these legume species have the potential to provide a wide and reliable flowering window, abundance of resource leading to reduced hive movement, opportunity for new honey markets, maintenance resource for pollinator health and rapid restoration in the event of decline and damage to local floral resources. We also know the flowering patterns of these legumes and how seasonal conditions may affect these patterns.

The UWA pasture team has begun characterising commercially grown pasture legumes in commercial fields and under controlled conditions with regard to their bee attractiveness and accessibility and the nutritional content of their flowers. Floral abundance and morphology, pollen quality, nectar volume and quality are also being examined. The team has already identified several species of annual and perennial legume pasture species that may provide excellent floral resources for European honey bees in Australia.

These honey samples are being analysed by for their bioactive properties. Initial results are very promising. These species are providing a long flowering window and early analysis suggests that their pollen and nectar are suitable to provide nutritious resources for honey bees.

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

24: The Bee Team (from left) Professor Megan Ryan, Dr Joanne Wisdom, Daniel Kidd and Dr Kevin Foster.

25: Two legume crops grown in pollination cages with different flowering times to assess their nectar and honey quality.

Diversity in waterlogging tolerance and other agronomic traits in subterranean clover (*Trifolium subterraneum* L) ssp. *yanninicum*

Project team: Professor William Erskine[1] (project leader; william.erskine@uwa.edu.au), Professor Megan Ryan[1], Dr Phillip Nichols[1], Dr Kevin Foster[1], Professor Yoshiaki Inukai[2], Dr Takao Oi[2]

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

Trifolium subterraneum L ssp. *yanninicum* is widely grown in medium and high rainfall areas of southern Australia because of its higher tolerance to winter waterlogging than the other two subspecies of subterranean clover. This project aims to evaluate agronomic traits associated with adaptation, animal health and resilience in the context of climate change within the Australian collection of ssp. *yanninicum* to determine the variation and trade-offs among desired traits of interest to meet climate adaptation and mitigation. Additionally, root functioning and physiological mechanisms will be studied in more detail in contrasting genotypes to identify if there is potential overcome weaknesses of current cultivars and increase sustainable growth of ssp. *yanninicum* in the southern Australian environment.

The project is part of the International Collaborative Program in Agricultural Sciences between Nagoya University and UWA. The experiments, will be conducted at, and supervised by, both institutions. Additionally, the project helps build research capacity for the Annual Legume Breeding Australia (ALBA) Joint Venture between PGG Wrightson Seeds and UWA.

Our results confirmed the existence of high diversity within 118 genotypes of ssp. *yanninicum* (107 wild accessions and 11 cultivars) for agro-morphological and isoflavone traits corresponding to eco-geographic attributes of collection sites. The acquired data are vital to enhance knowledge of distribution, adaptation, productivity and competitive success of ssp. *yanninicum* for breeding and selection programs. This project also showed the superior waterlogging tolerance of ssp. *yanninicum* compared tothe other two subspecies of subclover which resolved conflicting results from previous studies and an improved understanding of traits to meet the challenges of waterlogging for annual pasture legumes.

In 2020, waterlogging tolerance among the 32 genotypes of ssp. *yanninicum* (28 wild accessions and 4 cultivars) was assessed. The genotypes were selected based on availability and diversity of geographic coordinates and diversity in flowering time. We have collected data for morphological and physiological traits including seed weight, hypocotyl length, cotyledon size and cotyledon weight, leaf size, petiole length, leaf chlorophyll content, leaf isoflavone content, surface root growth, root and shoot dry weights and relative growth rates. We are currently analysing data.

This research is supported by the RTP, Science Industry PhD Fellowship (WA Government) and ALBA.

26: Glasshouse experiment for variation of waterlogging tolerance among 32 genotypes of ssp. *yanninicum*.

27: Surface root growth of ssp. *yanninicum* under waterlogging conditions.

The Ord River in Kununurra, The Kimberley.
Photo: Tourism Australia

3

Water for Food Production

Theme Leaders

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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 rain-fed agriculture.

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

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

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

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

Quasi-3D mapping of soil moisture for agriculture using electric conductivity sensing

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

Collaborating organisations: [1]UWA; DPIRD

Knowledge of real time spatial distribution of soil moisture has great potential to improve yield and profit in agricultural systems. However, rapid and precise quantification of water in crop fields is challenging due to the influence of highly variable soil properties such as texture and porosity. Mobile, non-destructive or minimally intrusive geophysical technologies are becoming popular for soil sensing in agriculture. Among these geophysical methods, electromagnetic induction (EMI) may provide a relatively simple and inexpensive method to assess variation in salinity, texture and moisture in fields. These sensors have single frequency multiple coil arrays to measure apparent electrical conductivity at different depths simultaneously, which is a function of soil properties like moisture, organic matter, texture, bulk density (ρ), and depth to subsurface horizons, stratigraphic layers or bedrock.

The aim of this study is to predict field scale soil moisture from ECa measured by a multicoil non-contact Dualem-1HS instrument and to explore the potential of inversion algorithms to establish layer conductivities for profiling individual layer moisture content. EMI surveys were conducted at sites in the Wheatbelt regions of Cunderdin, York, Pingelly (UWA Farm Ridgefield) and CRC for Honey Bee Products sites at Badgingarra, Kukerin, Wilga). These soil-mapping surveys were completed under variable moisture conditions in 2019. Along with these measurements, representative soil cores of 1m depth were taken and analysed from all the sites.

Much of the field data has now been collected for this PhD. Laboratory work relating electrical resistance tomography (ERT) and soil water for the different textures is continuing. The longer-term objective is to develop a fast and cost effective way of mapping soil moisture variability in broadacre fields of WA. This will provide farmers with crucial soil moisture information to make informed crop management decisions.

This research was supported by the RTP, UWA, GRS for International Travel and CRC for Honey Bee Products.

1: Dualem-1HS soil mapping setup.

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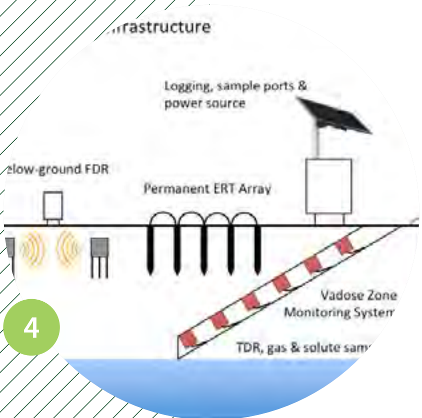


Generating soil moisture profile using deep learning based on satellite data: a case study of the WA wheatbelt

Project team: Atbin Mahabbati[1], Professor Jason Beringer[1] (project leader; jason.beringer@uwa.edu.au), Dr Matthias Leopold[1]

Collaborating organisations: [1]UWA; The OzFlux Network

Soil moisture affects crops growth by controlling the water budget between the soil and the atmosphere. Therefore, soil moisture is an indicator of water stress for vegetation and is used to monitor agriculture drought, which a prominent factor in efficiently using fertilisers, particularly when the fertiliser is supposed to apply under the surface. However, the current model's soil moisture estimations are not well suited for field-scale applications due to their coarse resolution (e.g. 5km provided by the Australian Water Availability Project).

With the rapid development of artificial intelligence in recent years and having access to advanced satellite images that provide high-resolution images, developing deep learning models can be a feasible solution to address our lack of almost real-time soil moisture data. Considering the significant superiority of deep learning models over traditional methods in image processing, time series analysis, and solving extremely complex problems, our aim is to construct and optimise a soil moisture estimation model to achieve high-precision assessing soil moisture profile across the WA wheatbelt.

In order to build such a complicated model, we have been cooperating closely with the UWA Department of Computer Science and Software Engineering (CSSE) experts and successfully designed a step-by-step road map, which includes all required details (e.g. the required form of input data, the data sources, the most suitable deep learning methods, etc.) during late 2020.

Providing a daily 3D map of soil moisture profile across the wheatbelt, the model would help farmers in almost any case where they need a reliable estimation of soil moisture. 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 production and benefits of farms.

This research was supported by the RTP, UPA living allowance 2017 and UWA Safety Net Top-up Scholarship 2017.

2: PhD student Atbin Mahabbati.

ARC Funding will build one of Australia's first Critical Zone Observatories at the Ridgefield Farm

Project team: Associate Professor Sally Thompson[1] (project leader; sally.thompson@uwa.edu.au), Dr Matthias Leopold[1], Professor Jason Beringer[1], Juraj Farkas[2], Wayne Meyer[2], Martin Andersen[3], Martin de Kauwe[3,4], Dr Jamie Cleverly[5], Associate Professor Andrew Marshall[6], David Chittleborough[2,6]

Collaborating organisation: [1]UWA; [2]University of Adelaide; [3]UNSW; [4]Bristol University, UK; [5]University of Technology Sydney; [6]University of the Sunshine Coast

A team of researchers lead by UWA has been awarded $2.25 million to establish an initial network of five Critical Zone Observatories (CZOs) in Australia with the WA node of the network to be based at UWA Farm Ridgefield. The Critical Zone spans the vertical area from the top of plant canopies to the point where soils meet fresh bedrock, and it is the vertical region in which all land based life is found. Studying this region as an entity is a relatively new, but accelerating, scientific activity around the world. The new network will be the first network of CZOs in the Southern Hemisphere.

Each OzCZO site will have the capability to measure reservoirs and fluxes of energy, carbon, water, and solutes across the critical zone using a variety of state-of-the-art equipment. At UWA Farm Ridgefield, the CZO will offer insights into how the ancient landscape there mediates fluxes of water, carbon and energy. The results will be important for benchmarking agricultural water management, carbon farming and carbon balance, for managing salinisation and for understanding the resilience of wheatbelt landscapes to changing climate.

This research was supported by the Australian Government and UWA.

3: The network (nicknamed OzCZO) includes five core and five satellite sites.

4: OZCZO below-ground and terrestrial CZ observational instrumentation. The mix of pre-existing and new instrumentation shown here is applicable to most sites in OZCZO, although two sites will also obtain new terrestrial eddy covariance systems through the project.

Dynamics of nitrate and nitrite in saturated sand filters with enhanced substrate conditions for denitrifying bacteria

Project team: Dr Rasha Al-Saedia[1,2], Adjunct Professor Keith Smettem[1], Dr Katia Stefanova[1], Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]Mustansiriyah University, Iraq

In this research, substrate conditions for denitrifying bacteria were enhanced by adding carbon sources to a laboratory-scale sand filter system. Temperature, oxidation–reduction potential, and hydrogen ion concentration were measured through the recirculation of nitrogen-dosed wastewater and carbon sources that were mixed to encourage microbial growth, with denitrifying bacteria identified by standard plate counts. Two different external carbon sources (sucrose and ethanol) were added, with and without activated sludge amendments. Nitrate, nitrite, and chemical oxygen demand (COD) concentrations were monitored relative to an untreated control and a treatment with activated sludge under an initial hydraulic loading rate of 0.508 m3 /m2 d and a hydraulic retention time of 2.5 hours.

Nitrate decay rates were only significantly enhanced for the ethanol treatment without addition of activated sludge. Nitrite initially accumulated when carbon sources were added, but no accumulation was evident by the end of the experiment after 150 min. COD declined when carbon sources were added, but activated sludge had no effect on the rate at which the COD declined. The increased rate of nitrate removal with the addition of ethanol is of technical interest, as the volume of wastewater treated in a unit volume of filter medium for denitrification doubled with ethanol compared with sucrose at the same concentration.

This research was supported by UWA and the HCED.

5: UWA PhD student Rasha Al-Saedi.

Forest loss in the Maritime Continent (our nearest neighbours) contributes to rising temperatures

Project team: Dr Octavia Crompton[1], Associate Professor Sally Thompson[1] (project leader; sally.thompson@uwa.edu.au), Dr John Duncan[1], Dr Debora Correa[1], Professor Michael Small[1]

Collaborating organisation: [1]UWA

Among the many negative environmental consequences of tropical deforestation in the Amazon Basin, Congo Basin and Southeast Asia, increases in temperature pose immediate threats to crop productivity and food security and human health. We are researching how much land clearing causes temperatures to rise in Maritime South East Asia, also known as the Maritime Continent (MC). Here, land clearing often occurs due to the establishment of large-scale plantation agriculture (principally oil palms), or due to small-holder agricultural expansion.

Our findings so far indicate that the temperature increases due to land clearing in the MC average around 3°C in completely deforested areas. However, where deforestation occurs on smaller spatial scales, so that there is more contact between forested and non-forested areas, these increases are reduced – e.g. an increase of 30 per cent in forest edges reduced the warming by 0.7°C. Additionally, warming due to loss at a point can spread in space to areas where no forest loss occurred, with areas up to 4km away from forest loss still experiencing warming.

The results, which are supported through at National Geographic Explorers AI for Earth Grant, suggest that (i) preventing clearing in proximity to farms may benefit agricultural productivity by avoiding the warming associated with clearing, and (ii) where clearing is essential, maintaining small areas of clearing and extensive interfaces with forests will minimise the resulting temperature rises. The research team is currently working on a web-mapping interface to show how temperatures could be expected to rise in the proximity of forest loss in the MC.

This research was supported by the AI for Earth National Geographic Explorers program.

6: An aerial view of cleared oil palms hillside at Kedah, Malaysia.

7

Deficit irrigation improves maize yield and water use efficiency in a semi-arid environment

Project team: Dr Zou Yufeng[1], Dr Qaisar Saddique[1], Dr Ali Ajaz[2], Dr Xu Jiatun[1], Dr Muhammad Imran Khan[3], Qing Mu[1], Dr Muhammad Azmat[3], Dr Huanjie Cai[1] (project leader; huanjiec@yahoo.com), Hackett Professor Kadambot Siddique[4]

Collaborating organisations: [1]Northwest A&F University, China; [2]Oklahoma State University, US; [3]National University of Sciences and Technology, Pakistan; [4]UWA

Maize is a part of staple diet in many developing countries and it is considered among the most important food sources (FAO, 2014). Maize also has the highest contribution in feed grain sector worldwide (CGIAR, 2016). With the ever-increasing world population, maize production needs to increase by 66 per cent by 2050 to meet the global demand. China is the second-largest maize-producing country, and Shaanxi province is the main production region in China.

Uncertainty in the availability of water supply pose challenges to traditional irrigation approaches. Regulating the amount and time of irrigation at different crop growth stages could provide a solution to optimize the irrigation water amid drought periods. This study evaluated the effect of different deficit irrigation levels on maize (*Zea mays* L.) at several growth phases over two growing seasons (2012 and 2013) in Yangling, Shaanxi province of China.

Maize grain yield in response to water stress (Ky, the yield response factor) was 0.66, suggesting that the environmental conditions of the study area favour the application of deficit irrigation. The maize yield response to reduced irrigation supply in this experiment indicated that regulated deficit irrigation might help growers to cope with decline in water availability during growing season.

This research found that:

- A combination of varying irrigation levels at different maize growth stages can help stabilising the yield under uncertain supply of water
- Reducing the full irrigation supply by 20 per cent between V8 to maturity overall had the highest yield
- Impacts of water stress during the early to mid-vegetative stages can be compensated by supplying 80 per vent or 100 per cent irrigation during the later stages, and
- Water stress at certain growth stages could have positive impact on maize yield.

This research was supported by the National Key Research and Development Program of China, National Science Foundation of China, and Program of Introducing Talents of Discipline to Universities, China.

7: Map location of Yangling field experiment and Wugong weather station in China.

Increasing maize production and preventing water deficits in semi-arid areas: A study matching fertilisation with regional precipitation under mulch planting

Project team: Dr Xudong Zhang[1], Professor Zhimin Li[1], Hackett Professor Kadambot Siddique[2], Professor Altyn Shayakhmetova[3], Dr Zhikuan Jia[1], Dr Qingfang Han[1] (project leader; hanqf88@nwsuaf.edu.cn)

Collaborating organisations: [1]Northwest A&F University, China; [2]UWA; [3]M. Kozybayev North Kazakhstan State University, Kazakhstan

Maize (*Zea mays* L.) is an important cereal crop that is widely used as food for humans and livestock, as well as raw material for industrial production. Maize production in semi-arid areas is increasingly at risk due to limited and uneven precipitation, and is further constrained by unvalidated nutrition management practices. Matching fertilisation levels to regional precipitation, however, can ensure sustainable water use and crop productivity.

From 2014–2017, a four-year field experiment was performed to evaluate the effects of fertilisation at five levels under two typical ridge-furrow mulch plantings (full plastic film mulching and half plastic film mulching) on soil water storage, maize yield performance, and water use efficiency in a rainfed semi-arid region of the Loess Plateau, China. This research:

- Found that full-film mulching maintained the water balance better than half-film mulching, and was better at promoting maize production within four years
- Demonstrated optimal matching of fertilisation and regional precipitation, and
- Established critical water deficit values as a warning system.

This research was supported by the National High-Tech Research and Development Program of China, Chinese Special Fund for Agro-scientific Research in the Public Interest, and Program of Introducing Talents of Discipline to Universities.

8: Maize crops near the mountains, north-west China.

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

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

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

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.

It aimed to understand the spatiotemporal variations of vegetation coverage and the response of evapotranspiration to vegetation restoration in the YanHe Watershed since 2000, explore the spatiotemporal characteristics and evolutionary trends of drought in the basin, and evaluate spatiotemporal variations and the influencing factors of soil conservation services.

The results of this study were used to analyse the excessive consumption of water resources caused by vegetation restoration in the YanHe Watershed during 2000–2015, and the significant role of vegetation restoration in restraining soil erosion. The research results are conducive to comprehensively evaluate the ecological effects of the GFGP, thereby provide a reference for ecological control on the Loess Plateau and guide the construction of ecological civilisation.

This research was 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.

9: Spatial correlation coefficient between SCM and ESI.

Precipitation dominates the transpiration of both the economic forest (*Malus pumila*) and ecological forest (*Robinia pseudoacacia*) on the Loess Plateau after about 15 years of water depletion in deep soil

Project team: Associate Professor Wenjie Wu[1], Dr Huijie Li[1], Dr Hao Feng[1,3] (project leader; nercwsi@vip.sina.com), Professor Bingcheng Si[2,4], Professor Guangjie Chen[1], Professor Tingfang Meng[3], Yue Li[1], Hackett Professor Kadambot Siddique[5]

Collaborating organisations: [1]Northwest A&F University, China; [2]Ludong University, China; [3]Chinese Academy of Sciences and Ministry of Water Resources; [4]University of Saskatchewan, Canada; [5]UWA

Understanding how different tree species consume soil water is critical for land management, especially in areas with limited water resources. This study examined the soil water consumption characteristics of two exotic tree species – economic forest apple tree (*Malus pumila*) and ecological forest black locust (*Robinia pseudoacacia*) – and the effect of soil desiccation on plant transpiration in the 2018 growing season in a semi-arid region of the Loess Plateau.

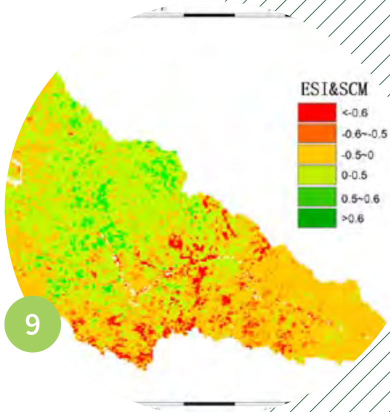
We investigated root distribution and deep soil water content in the vertical soil profile and used hydrogen and oxygen stable isotopes to identify the contribution of water to transpiration in shallow (0–2m) and deep (>2m) soil. We also measured sap flow changes using thermal dissipation probes during the growing season.

This research investigated water consumption of afforested apple trees and black locust on the Loess Plateau, and found that:

- Apple trees and black locust had a maximum rooting depth of 16m and 25m, respectively
- Water deficit below 2m reached 77mm for apple trees and 1926mm for black locust
- Great water deficit in deep soil forced trees to reply on shallow soil water, and
- Precipitation dominates the transpiration of the both species due to lack of deep soil water.

This research was supported by the National Natural Science Foundation of China, Fundamental Research Funds for the Central Universities, and 111 Project of the Ministry of Education and the State Administration of Foreign Experts Affairs.

8



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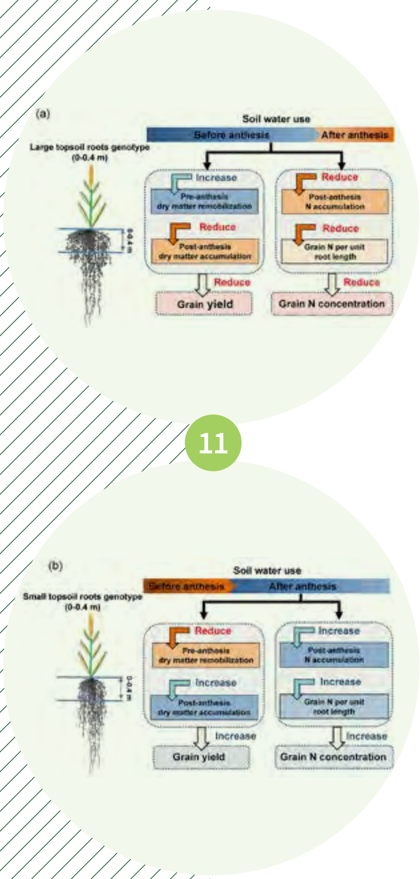
10: The ecological forest black locust (Robinia pseudoacacia) in bloom.



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

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

Wheat (*Triticum aestivum* L.) is most widely grown in arid and semi-arid areas. Most improvements in wheat yield in these regions have risen from selection based on shoot-related traits, such as the reduction in the height, which has been considered as one of the most successful agricultural innovations of the 20th century (Khush and Gurdev, 2001).

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 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.

This research found that:

- Wheat cultivars with small root mass in topsoil was associated with terminal drought tolerance
- Small root in topsoil improved grain yield and grain N under terminal drought, and
- The increased availability of soil water during grain filling enhanced post-anthesis biomass and N accumulation.

This research was 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.

11: Model of the wheat genotypes with contrasting topsoil root system affected grain yield and grain N concentration.

Measurements and modeling of hydrological responses to summer pruning in dryland apple orchards

Project team: Miaotai Ye[1], Dr Dr Xining Zhao[1,2], Dr Asim Biswas[3], Dr Gaopeng Huo[1], Dr Bo Yang[1], Dr Yufeng Zou[1], Hackett Professor Kadambot Siddique[4], Professor Xiaodong Gao[1,2] (project leader; gao_xiaodong@nwafu.edu.cn)

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

Drylands cover nearly half of the world's terrestrial land surface and support over a quarter of the global population's living space (Koutroulis, 2019). They are the main contributor to global food production (Plaza et al., 2018) and the optimal area of a variety of fruit trees due to abundant sunshine and large diurnal temperature variation. The expansive apple orchards in China's Loess Plateau provide the livelihood for about 10 million smallholder farmers. However, water scarcity results in an imbalance between supply and demand of water, hindering the sustainable development of apple orchards under more intensive droughts in drylands (Huang et al., 2016). Therefore, it is important to optimise water management strategies to reduce water consumption while maintaining yield.

This study examined the effects of multi-intensity summer pruning on water balance, production and water use efficiency of apple orchards on China's Loess Plateau using in situ measurements and the process-based MAESPA model.

A field experiment with four intensities representing no (0 per cent or control), light (10 per cent), moderate (25 per cent) and heavy (40 per cent) pruning of branches was carried out in three replicates under each treatment. The pruning intensities dictated transpiration, soil moisture and drainage. Although light pruning had weak impacts on these factors, moderate and heavy pruning significantly reduced growing-season transpiration by an average 10.4 per cent and 28.5 per cent, respectively. However, the effects progressively faded away with time at both diurnal and seasonal scales. Moderate and heavy pruning also increased soil water content in the 20–180cm by an average 18.3 per cent and 20.8 per cent, respectively, and thus enhanced drainage below 180cm (greater than 220mm), relative to light pruning and control (less than 170mm). Furthermore, light and moderate pruning clearly promoted apple yield and water use efficiency whereas heavy pruning significantly reduced (24.7 per cent) apple yield. Thus, moderate pruning can be a good choice for apple orchards in normal precipitation years while heavy pruning may be an alternative in severe drought years.

The MAESPA model reliably simulated seasonal variations of transpiration, soil evaporation, and profile soil water content for all treatments and can be used as a tool to quantify the effects of pruning on hydrological processes in dryland apple orchards. This study provides insights into the development of a sustainable management strategy in dryland orchards.

This research was supported by the National Key Research and Development Plan, 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.

12: Summer pruning of an apple tree.

13: China's Loess Plateau covers the world's largest area under apple trees.

Rainwater collection and infiltration (RWCI) systems promote deep soil water and organic carbon restoration in water-limited sloping orchards

Project team: Dr Xiaolin Song[1,2], Pute Wu[1,2], Professor Xiaodong Gao[2], Jie Yao[3], Dr Yufeng Zou[2], Dr Xining Zhao[1,2] (project leader; zxn@nwafu.edu.cn), Hackett Professor Kadambot Siddique[4], Dr Wei Hu[5]

Collaborating organisations: [1]Northwest A&F University, China; [2]National Engineering Research Center for Water Saving Irrigation at Yangling, China; [3]Baota District Fruit Bureau in Yanan City, China; [4]UWA; [5]The New Zealand Institute for Plant & Food Research

Water resources are severely limited in arid and semi-arid areas, which cover 30 per cent of the Earth's surface (Huang et al., 2008), due to climatic factors and poor land management (Giorgi and Bi, 2005). Growing demand for water, coupled with poor water management, has increased water stress in many parts of the world (Hoanh et al., 2015; Guterres, 2018). The hilly region of the Loess Plateau in China has a semi-arid environment (Fu, 1989; Fu et al., 2004) and is one of the most erodible places in the world; soil erosion has severely degraded soil quality and productivity in this area (Gao et al., 2018). Afforestation has been shown as an effective avenue to fight land degradation, facilitate land development, and improve soil quality (Feng et al., 2016; Wang et al., 2016).

Apple (*Malus pumila* Mill) is one of the main perennial fruit trees planted in northern China. Access to soil moisture is a significant issue for rainfed apple orchards established on sloping land on the Loess Plateau of China, where water resources are scarce.

Measures that maximise in situ infiltration and utilisation of rainfall are urgently needed on the Loess Plateau to minimise problems associated with drought and soil erosion, and to improve the sustainability of arid and semi-arid agricultural production in this region.

This research includes a two-year field assessment of two rainfall control systems – a rainwater collection and infiltration (RWCI) system and a semi-circular basin (fish-scale pit, FSP) – that could improve soil water storage (SWS) and deep soil organic carbon (SOC) levels in apple orchards on a slope. The RWCI system performed better than the FSP system at conserving and utilising rainwater resources and conserving rhizosphere soil water to meet the water demand of commercial apple orchards.

The RWCI system decreased the soil water storage deficit (WD) and enhanced the SOC content of the root zone due to precipitation, whereas the FSP had little effect. The RWCI system significantly increased soil water and SOC contents by 73 per cent and 81 per cent, respectively, relative to the control. The design depth of the RWCI system should match the root distribution of adjacent crops to make RWCI a recommended sustainable approach for maximising the utilisation of rainwater resources and the conservation of rhizosphere soil water in standing orchards. This system should help to mitigate the effect of climate change on water scarcity in arid and semi-arid regions, with potential for application in other orchard crops and regions.

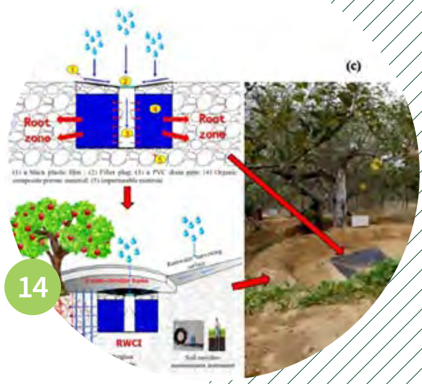
This research was supported by the China National Key Research and Development Plan Project, National Natural Science Foundation of China,111 Project, Integrative Science-Technology Innovation Engineering Project of Shaanxi, Shaanxi Key Science & Technology Innovation Team Project, and Major projects in Yangling Demonstration Area.

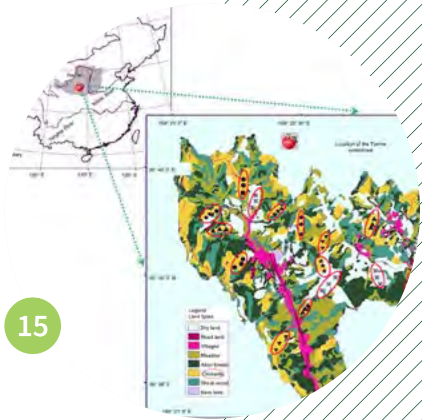
14: Depiction of a rainwater collection and infiltration system (RWCI). (a, b) schematic diagrams, and (c) field photograph.

Vertical variation in shallow and deep soil moisture in an apple orchard in the Loess hilly-gully area of north China

Project team: Xiaolin Song[1], Professor Xiaodong Gao[1], Dr Yufeng Zou[1], Dr Henry Chau[2], Dr Pute Wu[1], Dr Xining Zhao[1] (project leader; xiningz@aliyun.com), Hackett Professor Kadambot Siddique[3]

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





The Loess Plateau is one of the largest production zones for the apple industry in China, as growing conditions in this region are optimal for apple yield and quality.

Soil moisture is the main yield-limiting factor in arid and semi-arid regions (Gao, Zhao, Wu, Brocca, & Zhang, 2016). Water shortages especially during the reproductive stage can significantly reduce the yield and quality of fruit trees. Groundwater reservoirs in the Loess Plateau are too deep to contribute to soil evaporation and/or plant transpiration losses. Deep soil moisture, however, has a medium- to long-term residence time that serves as a bridge between shallow soil water and deep groundwater. Moreover, deep soil moisture (usually more than 2m) is especially important for sustaining plant growth and ecosystem sustainability in the semi-arid Loess Plateau.

Characterising the spatial variation of deep soil moisture is important for water management in apple orchards. Using a space-for-time substitution approach, we analysed the spatial variation of soil moisture content (θ) in 0–8m soil profiles in a dry year (2015, precipitation: 392mm) in rainfed apple (*Malus pumila* Mill.) orchards of various ages.

The soil moisture surveys revealed that effective water management through various water regulation measures at the 0.6–2.0m soil layer is essential for the sustainable development of apple orchards and reducing drought stress on the Loess Plateau and, potentially, other semi-arid orchards.

This research was supported by the National Key Research and Development Plan, National Natural Science Foundation of China, 111 Project, Integrative Science-Technology Innovation Engineering Project of Shaanxi, Key Science & Technology Innovation Team Program of Shaanxi Province, and major projects in Yangling Demonstration Area.

15: Location of study area and sampling sites in the rainfed apple orchards of the Tianhe watershed on the Loess Plateau of the northern Shaanxi Province, China.

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[1], Dr Xining Zhao[1,2] (project leader; xiningz@aliyun.com), Professor Xiaodong Gao[1,2], Ruhao Jia[1], Menghao Yang[1,2], Associate Professor Xiaolin Yang[3], Dr Yong Wu[4], Hackett Professor Kadambot Siddique[5]

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

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.

This research uses 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 crop are suitable for growing in semi-arid or dry sub-humid areas. Moreover, soil improvement and fertiliser 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 200kg 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 was 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.

16: 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.

Understanding different modes of runoff generation essential for soil and water conservation on agricultural lands in the Ethiopian Highlands

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

Collaborating organisations: [1]UWA; [2]University of California, Berkeley

An ongoing partnership between UWA and the University of California, Berkeley, is investigating how detailed understanding of soil properties, soil profiles and runoff generation mechanisms can inform the design of soil and water conservation facilities in the Ethiopian Highlands. This region, which experiences some of the highest rates of fluvial erosion in the world, has a wet summer growing season. A combination of field sampling, laboratory soils analysis and detailed modelling using one and two-dimensional soil water flow software is now revealing several important insights into how soil and water conservation measures must proceed.

Using detailed soil profile information, we are showing that current approaches of characterising runoff based only on soil surface properties is likely to lead to mischaracterisation of the main erosion processes. Water flow models show that reducing erosion is most sensitive to agricultural choices that can de-saturate soils, and that the most important plant property to achieve this outcome is waterlogging tolerance. The results will be used to suggest avenues for soil surveying, extension, variety development and exploration of the agro-ecosystem mixes needed for sustainable agriculture in the highlands.

This research was supported by the US National Science Foundation.

17: The Ethiopian Highlands near Lalibela.

Chardonnay grapevines in the Margaret River region, WA.
Photo: Chris Smith

4

Food Quality and Human Health

Theme Leaders

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Health attributes of foods are an important driver for food choices and UWA has strengths in developing and validating healthy foods and food ingredients.

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

The theme integrates complementary skills, knowledge and activities across disciplines at UWA, in collaboration with researchers from within and outside Western Australia, and relevant industries and their representative bodies.

Rediscovering Asia's forgotten crops to fight chronic and hidden hunger

Project team: Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au), Dr Xuan Li[2], Dr Karl Gruber[1]

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

The Asia Pacific region has seen improved food security over the past decade but continues to face a high prevalence of hunger and malnutrition. The prevalence of stunting (low height for age) and wasting (low weight for height) in the region remains high, with estimations that more than 77 million children under five years of age were stunted and more than 32 million were wasting in 2018.

Asia has a rich variety of edible and highly nutritious 'neglected crops', domesticated since ancient times but mostly forgotten or underutilised today. Just three staple crops – rice, maize and wheat – provide about 60 per cent of the world's food energy intake. This study found that diversifying agricultural systems to incorporate a wider range of nutritious and resilient crop species was the key to fighting hunger and malnutrition. Such an approach was proposed by the United Nations (UN) Food and Agriculture Organization's (FAO) Zero Hunger initiative in Asia, which aims to end hunger by 2030.

The researchers identified more than 150 species of food crops that were commonly used in Asia since ancient times were now neglected in favour of mainstream staple crops. They ranked various crop species according to their nutritional value, resilience to climatic change, economic viability, local availability and adaptability. Thirty-eight of the highest-ranking species were classified as Future Smart Foods (foods that are nutrition dense, sustainable, climate resilient, economically viable and locally accessible) – including foxtail millet, drumstick, lentil, elephant foot yam and taro.

The drumstick, also known as *Moringa oleifera*, is an outstanding example of a Future Smart Food because it is highly nutritious, drought-tolerant and grows from both cuttings and seed. Its leaves, flowers and pods are excellent sources of protein, and contain high levels of vitamins A, B and C, calcium, iron, potassium and magnesium. Additionally, compared to polished white rice, lentil contains three times more protein, six times more calcium, 25 times more dietary fibre and contains the most folate out of all plant-based foods.

Governments have a central role in the transformation of current agriculture and food systems. Our current over-reliance on staple crops as a leading cause of persistent malnutrition, coupled with low dietary diversity in Asia, should inspire policymakers to introduce these crops into mainstream agriculture and food systems. In South Asia, Nepal is an example where Future Smart Foods have been successfully implemented at different levels. Promising recent reports show significantly reduced signs of stunting and wasting in Nepalese children under the age of five years.

This research is supported by UWA and FAO.

1: Farmer's market vendors in Lobesa Village, Punakha, Bhutan.

2: Drumstick tree and pods (*Moringa oleifera*).
Photo: Hackett Professor Kadambot Siddique.

The interaction of household agricultural landholding and Caste on food security in rural Uttar Pradesh, India

Project team: Dr Srinivas Goli[1] (project leader; srinivas.goli@uwa.edu.au), Professor Anu Rammohan[1], Sri Priya Reddy[2]

Collaborating organisations: [1]UWA; [2]Jawaharlal Nehru University, India

Rural livelihoods are evolving. As individuals move towards non-farm livelihoods, it is critical to understand the role that remittances may play in supporting household food and nutrition security. Recent studies on the agriculture-nutrition disconnect and its implications for farming systems, especially in South Asia, have revived the debate surrounding the relationship of food security to household agricultural landholding (HAL). In rural India, food security, HAL, and social hierarchy (Caste) are closely connected. However, lack of empirical research on their interlinkages creates a knowledge gap that limits the formulation of evidence-based policies.

In this study, we used data from a unique survey of 5,087 rural households in Uttar Pradesh (UP) state in India to empirically assess the links between Caste, HAL, and food security. This study was the first in India to follow the same cohort of children over an 11-year period. It provided robust quantitative evidence of the impact of land ownership on child anthropometrics.

This research showed that both independently and collectively, Caste and agricultural landholding have a significant bearing on household food insecurity levels. 94 per cent of all food-insecure households report to hold no HAL or are holding marginal HAL. The predicted probability of food insecurity for households with no HAL is four times higher compared to medium-to-large HAL. Marginalised Castes (e.g. Hindu and Muslim Dalits) have three-to-four times more likely to experience food insecurity compared to their counterparts. The interaction effects of Caste-HAL suggest that marginalised Castes with no landholding are the most vulnerable groups for food insecurity. Thus, we suggest considering the role of Caste and HAL based inequalities and their interaction effect in policies adopted by the state for ensuring accessibility and availability of food among households in rural UP.

This research is supported by GIDS and ICSSR.

3: Sunset in rural Uttar Pradesh.

4: UWA Professor of Economics Anu Rammohan.

Environmental effects detrimental to citrus fruit quality managed through protected cropping

Project team: Dr Bronwyn Walsh[1] (project leader; industrymanager@wacitrus.com.au), Dr Joanne Wisdom[2], Professor Marco Ghisalberti[2], Dr Michael Considine[2], Kevin Lacey[3]

Collaborating organisations: [1]WA Citrus; [2]UWA; [3]DPIRD

This research project aims to provide the WA citrus industry with new knowledge via research activities for improving fruit quality as well as new production system in WA conditions.

These contribute to the citrus industry's strategic objective of increasing first grade pack-outs particularly for export markets. Current barriers include external peel quality issues such as albedo breakdown and wind scarring.

Preliminary investigation indicates possible links between environmental conditions (such as temperature and wind) and physiological processes (such as water transport and calcium deposition) within the citrus tree that affect evapotranspiration and ultimately albedo breakdown. Additionally, this research brings together previously independent research into wind blemish and albedo breakdown.

The project scoping period includes the investigation of current practice and available literature, industry-wide consultation, installation of a large-scale netting trial, weather monitoring technology, a suite of anemometers and sap flow sensors (to aid climatological modelling such as temperature and wind at orchard scales) and engagement with intensive wind modelling specialists from the UWA School of Engineering.

This research is supported by UWA, DPIRD and the WA citrus industry.

5: A protected cropping system.

6: Wind scarring and albedo breakdown on citrus fruit.

Discovery of differentially methylated DNA during bud dormancy in grapevine

Project team: Leni Campbell-Clause[1], Dr Michael Considine[1] (project leader; michael.considine@uwa.edu.au)

Collaborating organisations: [1]UWA; DPIRD

Bud dormancy is an important developmental transition in woody perennials. It enables the calibration of quiescence and growth cycles to environmental cues and is distinct from apical dominance. Epigenetic regulation has been known to influence environmental impact on developmental transitions in plants, including flowering, but its function in bud dormancy is underexplored. Grapevine is the most economically important fruit crop in Australia and worldwide. Epigenetic modification plays an important role in regulating development in response to environmental cues. Dormancy in perennial buds has been associated with regulated histone methylation of specific loci, however this does not appear to be widely conserved across species e.g. poplar and tea. DNA methylation remains underexplored in the context of bud dormancy.

The discovery of differentially methylated DNA during bud dormancy of the grapevine will provide further insight into how effective epigenetic regulation of DNA is, which areas in the genome are more susceptible to changes in methylation and whether there is a high level of epigenetic regulation on bud dormancy in grapevine. This information will expand our understanding of dormancy cycles in grapevines and other perennial species. The approach is less technically challenging than methods to study histone modification, such as ChIPseq. Hence, this research seeks to identify differentially methylated loci during dormancy in grapevine buds.

Epigenetic regulation of dormancy relates to other processes within the grapevine including growth and development, providing further avenues of research into perennial species' cultivation. The role of DNA methylation in regulating seasonal changes in bud dormancy requires further research and provides a tractable scope for investigation.

This research is supported by the ARC.

7: Seeking to identify differentially methylated loci during dormancy in grapevine buds.

8: Buds on a grapevine in a vineyard.

Improving table grape rootling propagation success

Project team: Dr Joanne Wisdom[1], Emeritus Professor John Considine[1], Dr Michael Considine[1] (project leader; michael.considine@uwa.edu.au), Colin Gordon[2]

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

The high quality of Western Australian table grapes commands a price premium, driving demand in new plantings and excellence in cultivar selection. This industry growth promotes rapid production of grafted table grape rootlings. However, nurseries are reporting unacceptable graft union failures. We recently met with producers and nurseries in Carnarvon to present findings from experiments designed to understand the effects of climate, physiology and genetics on the readiness state of grapevines to graft.

The diversity of table grape growing latitudes in Western Australia provides a unique opportunity to assess the ecophysiological effects on the 'growth readiness' status of the grapevine. Grafting is commonly used in woody perennial propagation to provide resistance to pathogens and improved plant performance. Grafting success requires a connection between a rootstock and the scion. This requires the formation of callus, a soft tissue that forms over a wound, on both sides of the union. However, the plant needs to be in a state ready for this type of cell growth. This shift towards such a pluripotent state is not well understood in grapevines.

In collaboration with Vinitech Nursery in the Swan Valley and GraftnGrapes Nursery in Carnarvon, we have investigated several aspects of grapevine growth readiness. As anticipated, plant material for propagation harvested from the lower latitude site in Carnarvon was slower to generate callus formation than material from the higher latitude Swan Valley. This was particularly noticeable at an earlier cane harvest time. We found that we could promote callus formation by exposing the plant to a chemical that promotes DNA de-methylation. This process essentially de-differentiates the cells making them ready to grow in a different way. Application of a commonly applied bud growth-promoting chemical was also found to be counterproductive to callus formation.

The findings from this research suggests that time of propagation material harvest, climate and cultivar are all important in influencing the readiness state of the grapevine to grow. Preliminary results suggest that plant material can be manipulated to ensure greater propagation success.

This research is supported by DPIRD, Vinitech Nursery and GraftnGrapes Nursery.

9: Callus formation on grapevine cutting.

10: Rootlings grown at GraftnGrapes nursery Carnarvon.

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 brings together the experts in new crop breeding methods in Australia and bean breeders in six partner countries in east Africa, led by The Alliance of Bioversity International and CIAT (CIAT-Uganda). 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 (CT) 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, and to distribute new varieties through the Pan Africa Bean Research Alliance (PABRA). 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.

During the first year (2019-2020), we surveyed the grain yield, CT, Fe and Zn content in more than 350 African bean varieties. We used genomic relationships to estimate genomic breeding values for each trait, incorporated them into an economic index, and generated an optimised mating design based on OCS. Crossing began in CIAT-Uganda in 2019. In 2020, we recalculated genomic breeding values based on additional information from CIAT-Uganda, and used OCS to begin a new round of crossing in four major marketing groups to match PABRA's bean breeding market targets in December 2020.

In 2020, six partner countries evaluated the parent lines in 15 field trials (distinct trials for bush and climber beans). All breeders and technicians at partner institutions were given training in the use of a common database Building Management Systems (BMS) which links trials across the partners. Partner countries will upload the field and laboratory data from these trials into BMS. Pedigree information will be combined with genomic information in BMS to permit analysis of genomic breeding values for grain yield, CT, Fe and Zn. Bean breeders in the six partner countries will be trained in design and analysis of field trials.

The progeny of cycle 1 are currently being evaluated for CT, Fe and Zn at CIAT-Uganda. Project partners will test seed of lines from cycle 1 in 2021 field trials, and will select locally adapted genotypes within known market classes.

After selection in each partner country, partners will release new bean varieties in relevant markets in east Africa through the CIAT-PABRA networks 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 and is abbreviated as BRÍO, standing for:

B Breeding values (BVs) accurately predicted from analysis of phenotypic and genomic and/or pedigree relationship data accumulated over cycles
R Rapid cycles of recurrent selection (two to three years)
Í Index selection on BVs weighted for economic value
O Optimised mating designs for sustainable and superior genetic gain

This research is supported by the ACIAR Project CROP.

11: Team members in a screen house at CIAT Kawanda.

12: Bush bean field trial in Ethiopia.

Enhancing turnip mosaic virus (TuMV) resistance for Brassica napus using the CRISPR/Cas system

Project team: Professor Jacqueline Batley[1] (project leader; jacqueline.batley@uwa.edu.au), Dr Philipp Bayer[1], Adjunct Professor Roger Jones[1], Linh Ton[1]

Collaborating organisation: [1]UWA

Turnip mosaic virus (TuMV), a potyvirus, is known to cause significant economic loss in vegetable crops, primarily in the Brassicaceae family. This virus is transmitted into Brassica plants in a non-persistent manner by over 89 aphid species, and the associated symptoms have been classified into 12 pathotypes, which limit the effectiveness of chemical control and general treatments. A novel genome editing tool, the CRISPR/Cas13 system (type II clustered regularly interspaced short palindromic repeats/associated Cas13 enzyme) has been a promising approach to fight against RNA virus infection in plants. In the CRISPR/Cas13 system, a single-guide RNA (sgRNA) can bind to the Cas protein, direct the complex to specific target sequences and proceed splicing.

In this research the CRISPR/Cas13 system will be used to interfere with TuMV infection in *B. napus*. The modified canola lines should express the CRISPR/Cas13 system specifically targeting and splicing the positive – sense single stranded RNA genome of TuMV, which could be useful for canola breeding improvement towards elevated TuMV resistance.

To date, whilst chemical-based pathogen control methods are known to be harmful to the environment and human health, enhancement of viral resistance for canola crops is a sustainable and environmentally friendly option.

This research is supported by the UWA International Fee Scholarship.

13: Maintaining TuMV by inoculation onto Brassica plants.
a) Brassica juncea and Sinapis alba inoculated with TuMV in a PC2 controlled environment room.
b) Juncea leaf with TuMV infection symptoms.

14: Turnip mosaic virus genome with potential regions for designing sgRNA associated Cas13 enzyme. The consensus TuMV genome generated from the 89 published complete genomes and the Australian TuMV isolate KX610932.1 using Geneious version 6.1 with similarities between 30 per cent to less than 100 per cent (greeny-brown) or 100 per cent (green). Potential targets for designing sgRNA depicted as red arrows.


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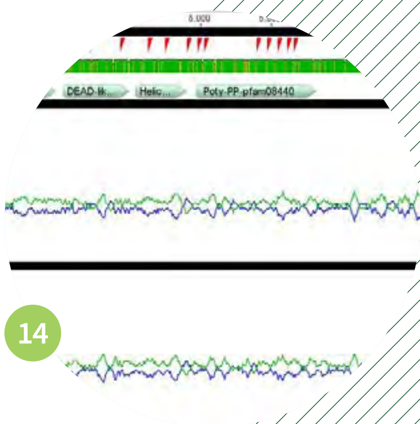

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Aerial drone photo of wheat fields harvested in WA.
Photo: Janelle Lugge

5

Engineering Innovations for Food Production

Theme Leaders

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The Engineering Innovations for Food Production 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.

Weed Chipper progresses to commercialisation

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]USyd; Precision Agronomics Australia

The targeted tillage "Weed Chipper" was developed around the simple yet effective modification of a standard cultivator with hydraulic breakout tynes. When a weed is detected, hydraulic solenoids are activated resulting in the tyne completing a hoeing type weed control action. The tyne essentially chips out the weed before returning to the standby position. The Weed Chipper can be towed by low-horsepower tractors at 10 to 15km/h. The Weed Chipper represents the development of an alternative, non-chemical weed control technology for Australia's conservation cropping systems. Dr Andrew Guzzomi and Dr Carlo Peressini, from UWA's School of Engineering and IOA, worked closely with David Nowland Hydraulics to design the mechanical system. The University of Sydney's Associate Professor Michael Walsh led the weed control testing, in partnership with researchers from The University of Queensland and the Queensland Department of Agriculture and Fisheries.

Since the GRDC research project ended in 2018, Dr Guzzomi and Associate Professor Michael Walsh have continued to pursue field demonstrations in WA, NSW and Queensland. In 2019, the Weed Chipper won the Rio Tinto Emerging Category at the WA Innovator of the Year.

The Weed Chipper is being commercialised by WA company Precision Agronomics Australia. It is expected that units will be available to farmers in late 2021.

This research was supported by the GRDC.

1: The UWA co-developed weed chipper in action.

Designing a deployment of Wi-Fi communications at UWA Farm Ridgefield

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

Collaborating organisation: [1]UWA

Led by Dr Dilusha Silva, a cohort of 100 students enrolled in Electrical Engineering Design 2 (Electrical 5552) investigated design options for effective establishment of fast internet and the deployment of WiFi communications across key locations on the UWA farm. The objective of each team of 6 students was to complete a detailed design of the system, followed by a virtual verification that the design satisfies the requirements. Given the restrictions imposed by COVID-19, a physical build of the sytem was not possible at the time. A group of 16 students from this cohort visited UWA Farm Ridgefield in October 2020, with the aim of taking measurements of mobile signal strength at various locations identified as an internet entry-point. The connectivity on the farm is presently very slow by modern standards and did not provide the communication bandwidth needed by the systems planned for the Future Farm 2050 project.

The students completed their designs and models in 2020. The next phase of the project will be to identify the best feature from these designs to be deployed on the farm in 2021/2022.

This research is supported by UWA.

2: UWA engineering students visiting UWA Farm Ridgefield.

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 comprises a multi-disciplinary research team with skills in agricultural engineering, pasture agronomy and plant breeding and physiology. The team is working with a range of leading pasture seed growers and seed companies in WA, SA, NSW and Victoria to develop innovative solutions to increase subterranean clover and annual medic seed harvesting efficiency and reduce soil erosion impacts of the vacuum seed harvesters commonly used. The project mainly focusses on subterranean clover but principles will also apply to annual medics.

In 2020, the project completed identification of the key issues affecting current subterranean clover seed harvesting methods, based on Horwood Bagshaw (HB) Clover Harvesters. These machines, manufactured from the early 1960s to the early 1990s, use suction to harvest clover burrs from dry soil over summer, following several passes with rakes and harrows to bring burrs to the surface. The project benchmarked the performance of current harvesting technology and examined a range of local modifications. The ageing HB clover harvesters were shown to be slow, inefficient in time and energy, left the soil highly prone to erosion and were becoming more difficult to repair.

Following research and evaluation of alternative harvest approaches, the project identified peanut harvesting as an avenue of exploration. A peanut digger-inverter was acquired in 2020 and tested at the UWA Field Station at Shenton Park. This machine was able to successfully cut, lift and invert subterranean clover rows at the field station. The harvester was then tested at a collaborator's farm in southern WA: this proved more challenging due to the farm's different soil and plant conditions. Further modifications to the peanut equipment have been outlined to improve performance; these will be evaluated in 2021.

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

3: PhD student Wesley Moss experimenting with the peanut digger at the UWA Shenton Park Field Station.

4: Members of the research team standing between the peanut digger-inverter and a vacuum clover harvester. From left: Wesley Moss, Dr Andrew Guzzomi, Dr Kevin Foster, and Associate Professor Phillip Nichols.

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Monitoring earthquake activity in the WA wheatbelt

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

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

In 2020, seismic monitoring continued from UWA Farm Ridgefield near Pingelly, in addition to about seven other sites in the WA wheatbelt.

Extra data has been obtained for approximately 200 events in the region in the past 12 months, as located by Geoscience Australia. This data is being used to improve the precision of the earthquake locations. About 70 sites have been identified in the wheatbelt region where earthquakes seem to repeatedly occur, and they represent locations of potential future earthquakes, have been identified. The WA wheatbelt is possibly the most seismically active region in Australia, but the reason for this remains unknown.

With the assistance of the Geological Survey of WA, two new monitoring sites were installed at Southern Cross and Hyden. Two research papers were presented to the annual conference of the Australian Earthquake Engineering Society: “Additions to the list of cluster centres in southwest Western Australia seismicity from 2017 to 2020”, and “The extent of the epicentral zone for events associated with two ML 5 events in March 2002 near Burakin, WA - a review of field and epicentral data”.

This research is supported by UWA.

5: The seismograph at the Southern Cross Resource Centre.

6: Dr Ruth Murdie in Meckering.

Multispectral imaging for characterisation of crop and animal products

Project team: Dr Dilusha Silva[1] (project leader; dilusha.silva@uwa.edu.au), Jorge Silva Castillo[1], Associate Professor Gino Putrino[1], Dr Michal Zawierta[1], Yuxiang Hu[1], Dr Seung Chul Yoon[2]

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

Low-cost multispectral cameras have the potential to revolutionise in characterisation of crop and animal products, as well as in the contamination testing in both. A new partnership between IOA researchers in the School of Engineering, with collaborators at the US Department of Agriculture (USDA) in Athens, aims to add multispectral capability into existing low-cost cameras to serve industry needs. This project was initiated by a visit from Dr Seung Chul Yoon to UWA in 2019, where he delivered a masterclass entitled “Hyperspectral Imaging – An engineering tool for agricultural applications”. This was followed by a visit from PhD student Jorge Castillo to the USDA, under the Buy West Eat Best Kim Chance Fellowship, over 2019 and 2020. During this time, Mr Castillo worked on hardware and software solutions to achieve this purpose.

In 2020, Mr Castillo presented his PhD research, titled “Low-cost portable spectral IMAGING system for poultry industry applications”, to a crowd of approximately 100 industry, research and university representatives at the IOA Postgraduate Showcase. This project is ongoing.

This research is supported by UWA and USDA.

7: A low-cost multispectral camera.

8: Simplification of faecal detection by using two wavelength bands. Line-scan hyperspectral camera attached with spectrograph. Credit: USDA

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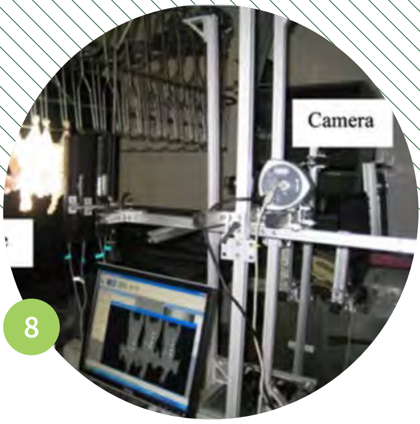

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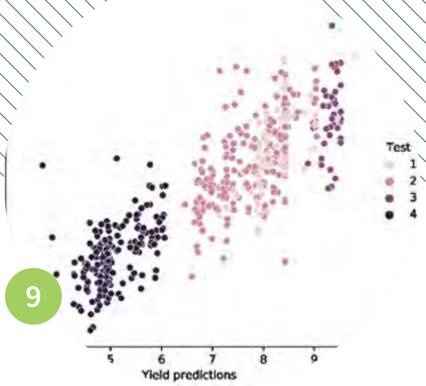

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Machine learning for climate-change-ready crops

Project team: Professor David Edwards[1] (project co-leader; dave.edwards@uwa.edu.au), Professor Mohammed Bennamoun[1], (project co-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 aims to bring machine learning, a form of artificial intelligence to the field as part of two GRDC-funded projects. The first project uses 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 has 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 applies machine learning to better understand the interaction between canola and its pathogen *Leptosphaeria maculans*, the cause of devastating blackleg disease. Project researchers have 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 have joined up with public and commercial partners in Australia and Europe to secure data access. Early results show high accuracy, already outperforming traditional statistical approaches.

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 GRDC.

9: Preliminary model predictions for yield across four locations show high accuracy.

10: Composite image of a field trial used to predict yield.

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Satellite prediction of forest flowering phenology

Project team: Daniel Dixon[1], Associate Professor Nik Callow[1] (project leader; nik.callow@uwa.edu.au), Dr John Duncan[1], Associate Professor Samantha Setterfield[1], Dr Natasha Pauli[1]

Collaborating organisation: [1]UWA

Flowering is both a key direct resource (e.g. nectar for honey), an indicator of potential yield and a critical phenological crop stage. Knowledge of flowering phenology is essential for understanding the condition of plants, but is highly variable within and between forest stands and across crops within paddocks. There are at present, very limited tools to monitor this at the scale of individual trees or within crops, and then understand this across forest ecosystems or farming bioregions to understand how various anthropogenic and environmental drivers impact flowering resources and timing.

This research uses remote sensing and geospatial tools to answer questions about flowering pehnology within the Jarrah-Marri forest that supports the honey bee industry, and has major implications for off-site pollination service provision, environmental health and food security. A new method has been developed that combines drone and satellite images (PlanetScope) that can produce landscape-scale maps of flowering dynamics. This method is demonstrated in forest landscapes dominated by the eucalypt *Corymbia calophylla* (red gum or marri) in WA. Drone-derived images of flowering eucalypt canopies, available for restricted temporal and spatial extents, are used to label satellite image pixels with the proportion of a pixel footprint that is flowering. The pixels labelled with flowering proportion, the response variable, are combined with various metrics that characterise time series of spectral indices sensitive to the presence of green vegetation and cream-colored flowers, the predictor variables. A machine learning model then predicts daily pixel-level flowering proportions. The model is trained with data from two sites and is tested with data from three sites and various dates throughout the *Corymbia calophylla* season. The model is able to accurately predict pixel-level flowering proportion throughout the flowering season across sites with dense to sparse canopy, different background soil covers, and is robust to not detecting false positive flowering when no flowering events are occurring.

Due to the spatiotemporal coverage of satellite images, this model can be deployed to generate regional maps of flowering dynamics in forest ecosystems that can be used for monitoring forest ecosystem condition and supporting research into drivers of eucalypt forest phenology. The work also has applications and potential to be re-tasked into an analysis of flowering within broadacre and horticultural crops.

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

11: UWA PhD student Daniel Dixon with a drone.

12: Satellite imagery of flowering tree canopies in southwest Australia.

Use of Light Detection and Ranging (LiDAR) to detect weeds that grow taller than wheat crops at harvest

Project team: Nooshin Shahbazi[1], Associate Professor Ken Flower[1] (project leader; ken.flower@uwa.edu.au), Associate Professor Nik Callow[1], Professor Ajmal Mian[1], Professor Hugh Beckie[1], Dr Mike Ashworth[2], Elliot Nicholls[3], Stuart Speidel[3], Michael Finn[3], Craig Brogle[3]

Collaborating organisations: [1]UWA; [2]AHRI; [3]Stealth Technologies

Weeds have a major impact on crop yields and their management is a key aspect of crop production. The majority of current weed control strategies are based on herbicides and often lack diversity, resulting in herbicide resistance. Harvest Weed Seed Control (HWSC) is one of the key non-herbicide control measures for weeds. However, weed species such as brome grass (*Bromus spp.*) and wild oats (*Avena fatua*) shed most of their seeds before harvest, thereby avoiding this important method of non-herbicide weed control. Many of these weeds are taller than the crops they grow in.

The aim of the project is to assess the capability of LiDAR (Light Detection and Ranging) to detect weeds that are taller than wheat crops and map their locations to allow targeted weed management in the following season.

Two field surveys were carried out in crop fields, before harvest in 2018 and 2019 in the WA central wheatbelt, to assess the main late weed species growing taller than the crops. The results showed that the main weed species that grew taller than the crop at harvest time were *wild oat*, wild radish (*Raphanus raphanistrum)* and sow thistle (*Sonchus spp.*). The results of these surveys were published in November 2020 in the journal Weed Research: “Comparison of crop and weed height, for potential differentiation of weed patches at harvest”.

In 2019, two trials were carried out at UWA. The first was to assess the diameter, height and distance of artificial targets that could be detected by LiDAR. In the other trial, the capability of LiDAR to detect weeds growing above wheat in a small plot was also tested. The results were published in March 2021 in the journal *Sensors*: “Assessing the capability and potential of LiDAR for weed detection”.

In 2020, the LiDAR was taken to the field at Cunderdin and used to locate weeds in a farmer’s wheat crop on two occasions. Initially, different weeds in pots were placed in the field among naturally occurring wild oats. The LiDAR was mounted on a moving vehicle and used to scan the area to determine if the weeds could be detected. On the second occasion, in a proof of concept, the LiDAR was attached to a harvester and used to scan across the cutting front of the harvester for weed detection.

This research is supported by the RTP, UWA Safety Net Top-up Scholarship 2018, Calenup Postgraduate Research Fund 2019 and AHRI.

13: Wild oat is one of the persistent weed species that are present in the crop until harvest with discernible height difference to the crop.

14: LiDAR can be attached to a harvester to detect and map the weed species at harvest.

Fruit and vegetables at a street market in Hanoi, Vietnam.
Photo: Cezary Wojtkowski

6

Agribusiness Ecosystems

Theme Leaders

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The agribusiness ecosystem is about the interconnectedness and linkages of agricultural enterprises with each other and with non-agricultural enterprises in the exchange of goods and services. The essence of the ecosystem is the creation of economic value, which is the focus of every commercial activity.

The term 'ecosystem' has its roots in biology. It represents an interaction of living organisms in conjunction with the non-living components of their environment such as water, soil, minerals, and air. The ecosystem exists because of the interconnectedness and relationships between and among the components in the system and their implied interdependencies. Therefore, the robustness of an ecosystem will depend on the strength of the bonds and interrelationships of the components or entities in the community.

The same is true with the agribusiness ecosystem. Agribusiness encompasses all the various business enterprises and activities from the supply of farm inputs, on-farm production, manufacturing, and processing to distribution, wholesaling, and retailing of agricultural produce to the final consumer. All those business enterprises along the value chain are interconnected. The success of any agribusiness firm does not depend only on how efficiently and effectively it is internally managed, but also on how it effectively co-opts the complementary capabilities, resources, and knowledge of the network of other firms and institutions in the same industry and beyond. This includes doing business with non-agricultural oriented businesses in banking and insurance among others and receiving services from government and educational institutions.

The aim of the Agribusiness Ecosystems theme at IOA 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 2020. Our research focus contributes to the realisation of the 2030 Agenda of Sustainable Development.

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Australia New Zealand agri-food industries highly resilient during COVID-19

Project team: Dr Val Snow[1] (project leader; val.snow@agresearch.co.nz), Professor Daniel Rodriguez[2], Robyn Dynes[1], William Kaye-Blake[3], Dr Thilak Mallawaarachchi[2], Dr Sue Zydenbos[2], Dr Lei Cong[4], Irena Obadovic[1], Rob Agnew[5], Nicole Amery[1], Lindsay Bell[6], Cristy Benson[1], Dr Peter Clinton[7], M. Fernanda Dreccer[6], Andrew Dunningham[7], Madeleine Gleeson[2], Matthew Harrison[8], Dr Alice Hayward[2], Dean Holzworth[1], Paul Johnstone[5], Professor Holger Meinke[8], Professor Neena Mitter[2], Dr Amin Mugera[9], Professor David Pannell[9], Dr Luis Silva[2], Professor Eugeni Roura[2], Prince Siddharth[3], Hackett Professor Kadambot Siddique[9], David Stevens[1]

Collaborating organisations: [1]AgResearch Lincoln Research Centre; New Zealand; [2]The University of Queensland; [3]NZ Institute of Economic Research, New Zealand; [4]Lincoln University, New Zealand; [5]Plant and Food Research, New Zealand; [6]CSIRO; [7]Scion, New Zealand; [8]The University of Tasmania; [9]UWA

COVID-19 (SARS-CoV-2) has had immediate and significant effects on peoples' health and the worldwide economy. The pandemic has led to unprecedented impacts on labour availability, provision of goods and services, value chains, and markets.

Against the backdrop of COVID-19 control measures, this research conducted quantitative and qualitative assessments of the impacts, adaptations, and opportunities to increase the resilience of the agricultural systems in Australia and New Zealand. Using both survey and in-depth interview methods, the researchers described the various agri-food systems and the impacts of the COVID-19 control measures across different industries, and discussed the results applying a resilience framework.

As essential services, all agricultural activities except for fibre production were permitted to continue during quarantine periods but were exposed to the major flow-on effects of movement control. We found that, to June 2020, the impacts of the COVID-19 control measures on the agri-food sectors in both Australia and New Zealand were relatively small, and that this has been due to the high levels of resilience in the agricultural systems and the people running them.

Agri-food systems were resilient up until June 2020 at least, when the survey was conducted, and that resilience was achieved via one or more subsystems that were able to compensate for the more vulnerable subsystems. Both high plasticity and rigid types of industries were resilient, but they achieved that resilience via compensating subsystems. High plasticity industries relied on their production and processing subsystem, while rigid industries engaged their institutional subsystem to achieve the same end. The social and cultural subsystem was important across all industries.

To capture longer-term effects and analysis during the more sustained effects of the virus and through a recovery period, a follow-up study is planned for 2022.

This research is supported by NZIER and UWA.

1: An apple orchard in Australia.

Australian Co-operative and Mutual Enterprise Index: Australia's leading co-operative and mutual enterprises in 2020

Project team: Winthrop Professor Tim Mazzarol[1] (project leader; tim.mazzarol@uwa.edu.au), Karl Coombe[2]

Collaborating organisations: [1]UWA; [2]BCCM; Cobargo Co-operative Society

The Australian Co-operative and Mutual Enterprise Index (ACMEI) is a longitudinal study that can provide a better understanding of these firms and their economic and social contribution to the national economy. This study is part of a long-term ACMEI project, with the goal of developing a comprehensive understanding of the size, characteristics, and impact of the CME sector on the Australian economy and society. This work is undertaken in conjunction with the Business Council for Co-operatives and Mutuals (BCCM).

This paper reports on a research study that maps the size and structure of the Co-operative and Mutual enterprise (CME) sector in Australia. In 2020, the study found 2,040 active CMEs, of which 81 per cent were co-operatives, 15 per cent mutual enterprises, 2.1 per cent were friendly societies and 2 per cent were member-owned superannuation funds. These firms had a combined active membership base of more than 28.7 million memberships, generated around $100 billion in revenue, managed more than $1,067 billion in assets, and employed at least 69,839 people. They encompassed a wide range of industry sectors and provided significant economic and social benefits to their members. The report outlines these contributions and offers a case study of a selected CME to illustrate them.

The National Mutual Economy report recognises the significant contribution of CMEs to the resilience of our communities and the economy. Is shows the sector is growing and facing profitability challenges before the advent of COVID-19.

This research is supported by the BCCM.

2: The Cobargo Co-Operative Society sign.

Value congruence between Australian small business member firms and their co-operatives

Project team: Winthrop Professor Tim Mazzarol[1] (project leader; tim.mazzarol@uwa.edu.au), Shahid Ghauri[1], Emeritus Professor Geoff Soutar[1]

Collaborating organisations: [1]UWA; Co-operative Bulk Handling Group; Capricorn Society; Geraldton Fishermen's Co-operative; WA Meat Marketing Co-operative

Scholarship within co-operatives has been fragmented and focused mostly at the macro and meso levels. Focusing on the small business members that join a co-operative (i.e. at the micro level), has received little attention. Members play four roles when they become a member of Co-operative, which can lead to conflict and tension between those managing the Co-operative versus those for whom the Co-operative was established in the first place. Previous research has identified the different roles played by co-operative members, but there has been little empirical evidence the members are fully aware of the different roles they play. In this research, we argue that this conflict and tension can influence the value proposition and intrinsic values at the micro and meso levels. This study intends to explore the four roles members play and how they moderate on the member value proposition and intrinsic values to achieve alignment, which should lead to increased member participation, which is critical for the Co-operative to survive and operate sustainably.

Small to Medium Enterprises (SMEs) can benefit from membership of a co-operative. This study aims to test previous antecedents of why SMEs join a co-operative. We interviewed members and executives of four Australian co-operatives to investigate reasons why SME owners joined them. All interviewees agreed that the Co-operative had to provide economic benefits in addition to information, business support, knowledge, and networking. The SME owners' disposition of collective action towards a common sense of purpose supported the decision to become a member of their co-operatives. Asset, temporal, location and relational specificity provided the external resources through their co-operative to challenge the environmental uncertainty the SMEs faced.

This research is supported by the Co-operative Enterprise Research Unit.

3: A farmer observing wheat in his field.

Engaging digital media to more effectively build confidence in use of sustainable land management practices

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

Collaborating organisations: [1]UWA; [2]South West Catchments Council; Dotsquares Pty Ltd

This digital media project is focussed on capacity building for sustainable natural resource management. It aims to strengthen capacity within the farming community in relation to sustainable land management by rolling out and monitoring digitally formatted soil health information. The focus on knowledge of soil biological processes is being presented in a user-friendly manner via the app 'soil health' to assist in building confidence in its application to improving the soil condition. Networks of the South-West Catchments Council (SWCC) are specifically being targeted as a precursor to general release within the agricultural community.

This project will provide essential information about complex aspects of soil health in a user-friendly digital format using the cross-platform app. The app will include a summary of key concepts related to management to capture benefits from soil biological processes in the format of an e-book, a series of podcasts based on best practice scientifically rigorous information and seven professionally produced animated videos that target key areas of biological components of soil health.

Progress during 2020 included the initial scoping for the design and development of the app and the subsequent completion of the alpha version of both the IOS and Android versions of the app. The seven video animations have been released through the SWCC and are embedded in the app. The podcasts are under development. Communication and use of the resources, when launched in 2021, will be in a collaboration with SWCC.

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

4: A field at UWA Farm Ridgefield near Pingelly.

5: Soil at UWA Farm Ridgefield.

Optimal lime rates for soil acidity mitigation

Project team: Sanaz Shoghi Kalkhoran[1] (project leader; sanaz.shoghikalkhoran@research.uwa.edu.au),
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Collaborating organisation: [1]UWA

Many agricultural soils are naturally acidic, and agricultural production can acidify soil through processes such as nitrogen (N) fixation by legumes and application of N fertiliser. This means that decisions about mitigation of soil acidity (e.g. through application of lime), crop rotation and N fertiliser application are interdependent. This paper presents a dynamic model to determine jointly the optimal lime application strategies and N application rates in a rain-fed cropping system in WA. The model accounts for two crop rotations (with and without a legume break crop), for the acid tolerance of different crop types, and for differences in the acidifying effect of different N fertilisers.

Results show that liming is a profitable strategy to treat acidic soils in the study region, but that there are interactions between N and acidity management. Choice of fertiliser affects optimal lime rates substantially, with the use of a more acidifying ammonium-based fertiliser leading to higher lime rates. The optimal liming strategy is also sensitive to inclusion of a legume crop in the rotation, because its fixed N can be less acidifying than fertiliser, and it allows a reduction in fertiliser rates. Higher rainfall zones have greater N leaching, which contributes to a higher optimal rate of lime. We find that injection of lime into the subsoil increases profit. Optimal lime rates in the absence of subsoil incorporation are higher than usual current practice, although the economic gains from increasing rates are small.

This research is supported by the RTP and ARC Centre of Excellence for Environmental Decisions.

6: An example of soil condition with lime.

Valuing WA's natural resources for beekeepers

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

Collaborating organisation: [1]UWA

WA's natural bushland and forests provide a unique opportunity to migratory beekeepers with year-round nectar and pollen supply for their European honey bees (*Apis mellifera*). Endemic vegetation to the south-west such as Jarrah (E. *marginate* sp.), Karri (E. *diversicolor*), Marri/red gum (*Corymbia calophylla*) and Manuka species (*Leptospermum* sp.) produce highly valued honeys with varied levels of antimicrobial properties. Coastal sandplain vegetation provide over-wintering food sources for colony health and spring population growth. However, with frequent burning, logging and clearing of natural bushland and forests coupled with altered flowering phenology, possibly due to climate change, the sustainability of the industry and growth is uncertain.

The industry now has over 3,700 registered beekeepers dependent on access to apiary sites and natural resources in the state. Amateur beekeepers (those with one to 40 hives) have had the largest growth in numbers and production of all in the sector and have the potential to move in to commercial beekeeping (more than 200 hives) and pollination services in the future. However, expansion is limited by availability of productive sites. The decline in the availability of nectar at apiary sites and the loss of sites may see commercial beekeeping decline in the future. There are approximately 4,500 apiary sites on public land with more than half not producing commercially viable nectar flows in any year. The number of apiary sites in backyards, on private land and on crops for pollination services are unknown.

The last comprehensive natural resource study of WA commercial beekeepers was by the Department of Agriculture in 1989-1990. We have digitised this 30-year-old survey data and applied today's average honey prices. Expected average honey production from bush sites on natural vegetation Interim Biogeographic Regionalisation for Australia (IBRA) sub regions were valued between $2,500 and $25,500 based on upper and lower honey quota prices. We have also conservatively estimated the loss of honey production as a result of burn incidents for a 38 year period (years 1980–2018). Fires and fire related honey production losses was estimated at 60 thousand tonnes, worth a present value of $273 - $539 million (wholesale packer prices).

Our research aims to update this data with a questionnaire for all beekeepers and an extension to the geographical area. Our Natural Resources for Beekeepers 2020-21 Questionnaire accommodates for different scales of production and use of natural resources across the south-west of WA. We will examine the geographical significance and economic importance of apiary sites and flora use in relation to year-round colony health and honey production. Results from our 2020-21 questionnaire will support industry with the provision of essential data for evidence-based policy analysis, particularly for decisions about land resource management for commercial beekeepers.

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


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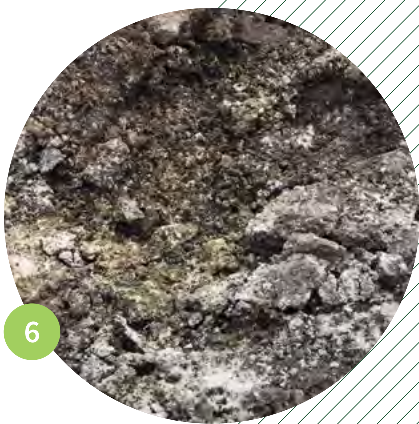
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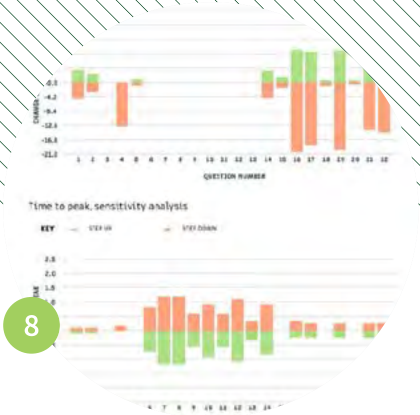
7: Honeybees on a native flowering gum. Photo: The Wildflower Society of WA.



Is it the model or is it the process of using it? Extension officers evaluate ADOPT as a tool to assist planning in the pastoral sector

Project team: Oscar Montes de Oca Munguia[1,2] (project leader; oscar.montes@scionresearch.com), Professor David Pannell[1], Dr Rick Llewellyn[1]

Collaborating organisations: [1]UWA; [2]Scion Research, New Zealand; CSIRO

Agricultural extension professionals are aware of the complexity surrounding farmers' decisions to adopt a new technology or practice. These extension officers often need to design strategies to improve adoption though planning processes, which are commonly run collaboratively by expert groups and through deliberation rather than individually. Models have been used to assist these deliberations, but it is not clear which aspects of the model or the deliberative process are more useful for extension planning.

In this study, we research how ADOPT (a model that predicts adoption) may assist decision making in planning for agricultural extension. In 2018, we used ADOPT in three workshops with extension officers from the pastoral sector in New Zealand to analyse the adoption of four well-known practices in the industry. We identified important features of the model and the process used in the workshops and asked participants to rank their usefulness. The components were: a conceptual model of adoption, a comparison between the predicted diffusion curve and actual uptake, a sensitivity analysis of the results, and a structured discussion around these components.

We found that using ADOPT changed participants' perceptions on the feasibility of forecasting adoption. We also found that participants believe the process of discussing and using ADOPT was just as important, or more important, than the model's results.

This research is supported by AgResearch and Landcare Research, the Red Meat Profit Partnership, and Dairy NZ.

8: ADOPT's sensitivity analysis diagram used to analyse the use of pasture management software.

Understanding adoption of innovations and behaviour change to improve agricultural policy

Project team: Professor David Pannell[1] (project leader; david.pannell@uwa.edu.au), Professor David Zilberman[2]

Collaborating organisations: [1]UWA; [2]University of California, Berkeley

Research on the adoption of new practices and new behaviours in agriculture continues to grow and evolve, and its relevance to policy remains high. This special issue presents 10 papers that provide overviews of important aspects of the recent adoption literature, or identify gaps and opportunities in the literature. Adoption research has been innovative in a number of ways, including its recognition of adoption decision making as a process, not an event; its emphases on heterogeneity and learning; and its strong multidisciplinary flavour.

There is scope for further innovation through efforts to enhance predictions of adoption, better understanding the balance between profit and non-profit motivations, and better recognising the influence on adoption of characteristics of the innovations, not just characteristics of the potential adopters and their contexts. Opportunities for policy include effort to support women farmers' adoption of beneficial innovations in developing countries, and use of tools and approaches from marketing in public extension programs.

This research is supported by the Department of Agricultural and Resource Economics at the University of California (UC), and UWA.

9: UC Professor David Zilberman.

10: UWA Professor David Pannell.

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

Project team: Associate Professor Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Professor Kalyan Das[2], Dr Ram Datt[3], Yuga Nath Ghimire[4], Associate Professor Md Farid Uddin Khan[5], Dr Md Mamunur Rashid[6], Adjunct Professor Roy Murray-Prior[7], Professor Renato Villano[8], Dr Jon Marx Sarmiento[8], Bibek Sapkota[1]

Collaborating organisations: [1]UWA; [2]University of Calutta, India; [3]Prasad Central Agricultural University, India; [4]NARC; [5]Rajshahi University, Bangladesh; [6]CQUniversity, Australia; [7]University of the Philippines Mindanao; [8]University of New England, Australia; Bihar Agricultural University, India; Uttar Banga Krishi Viswavidyalaya, India; RDRS Bangladesh

Since 2014, the Sustainable and Resilient Farming Systems Intensification (SRFSI) project field-tested conservation agriculture-based sustainable intensification (CASI) technologies in various farming systems. However, adoption has been patchy both inside and outside SRFSI trial sites. While economic advantages of CASI technologies are important, in many cases non-economic factors are critical to adoption. In this project, we explored both economic and non-economic factors affecting decision making, which include risk tolerance, farming objectives, social factors, perceptions of technologies, membership of associations, women's participation in decision-making, experience of climate events, perceived behavioural control, and availability of suitable manpower and supporting services, among others. It aims to investigate the additional insights into adoption of CASI technologies that can be obtained using behavioural economics theory and to use these to develop and test more efficacious interventions to improve adoption of CASI technologies.

Results from focus group discussions and key informant interviews suggest a high potential of the Farmer Behaviour Insights Project to contribute to increased adoption of CASI technologies due to behaviourally informed designed interventions. In India, there is a potential to increase farm mechanisation, especially, with the introduction of rice transplanters as it not only benefits the cultivators but also paves the way for economic empowerment of women farmers. Self-help groups, composed mostly of women, are motivated to cater to the need of doing the seedling factory business. In Bangladesh, farmers have appreciated the economic value of mechanisation in their farming systems. This has resulted in more interest to adopt CASI technologies. In Nepal, there is a good uptake of Zero Tillage Wheat technology. This will be the focus of intervention through establishing contract service agreement between farmer groups and service providers.

This research is supported by ACIAR.

11: Interviews with farming household in Rajshahi, Bangladesh.

12: Focus group discussion with women farmers.

Sustainable and resilient farming systems intensification (SRFSI) in the Eastern Gangetic Plains Scaling Project

Project team: Associate Professor Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Professor Kalyan Das[2], Dr Ram Datt[3], Surya Adhikari[4], Dr Md. Shakhawat Hossain[5], Dr Md Mamunur Rashid[6], Professor Roy Murray-Prior[7], Dr Jon Marx Sarmiento[8]

Collaborating organisations: [1]UWA; [2]University of Calutta, India; [3]Prasad Central Agricultural University, India; [4]NARC; [5]University of Missouri, US; [6]CQUniversity, Australia; [7]University of the Philippines Mindanao; [8]University of New England, Australia; Uttar Banga Krishi Viswavidyalaya, India; Bihar Agricultural University, India; Bangladesh Agricultural Research Institute; RDRS Bangladesh

Since the inception of SRFSI project in 2014, the development and promotion of conservation agriculture-based sustainable intensification (CASI) technologies in the Eastern Gangetic Plains (EGP) of South Asia continued. The project envisioned to develop more productive and sustainable technologies and facilitate adoption of these technologies among women and men farmers. This year, 2020, the SRFSI project has concluded, and crucial to the culmination of the project is the assessment of the impact of the SRFSI project to women and men farmers in the EGP.

This project explored both economic and non-economic factors to explain why adoption of CASI technologies has been relatively slow despite the well-recognised positive returns from adoption of these technologies. Notable changes were observed in the areas of demographic, health, education, investments, household, gender roles, personal and socio-cultural conditions of the farmers. In this project, we had a better understanding of the economic and non-economic impacts of CASI technologies and the drivers of its adoption. It also improved the participation of women farmers in SRFSI due to continuous understanding of how to better mainstream women farmers.

This research is supported by ACIAR.

13: In-depth interviews with women farmers in West Bengal, India.

14: SRFSI trial participation.

Does participation in local agricultural institution facilitate technology adoption and enhance crop yield?

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

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

This study examines whether agricultural institution membership (AIM) enhances the adoption of Laser Land Leveller (LLL), and measures the impact of AIM and LLL adoption on farm performances. The study applied Propensity Score Matching (PSM) to find comparable groups who have similar observable characteristics between LLL adopters and non-adopters. Application of PSM thus helped us to control for the bias due to confounding variables while estimating the treatment effect. Then non-parametric Data Envelopment Analysis (DEA) with bootstrapping and single-stage Stochastic Frontier Analysis (SFA) correcting for sample selection bias was employed to estimate efficiency accounting for observable and unobservable heterogeneity factors on farm performance. The output variable is total revenue from wheat production and the input variables are land, seed, labour, chemicals, machinery and irrigation. Wheat is used as a case study because it is grown in almost 30.54 million ha and is the major cereal crop for food security in India. Cross-sectional data collected in 2015 from three states of India – Haryana, Punjab and Uttar Pradesh – were used for this study. A household survey was conducted on 1000 farm households from selected districts under each state i.e., two districts from Haryana, three from Punjab, and two from Uttar Pradesh. A multi-stage sampling method was adopted to select farm households.

The results reveal that land ownership, family with migrant member, caste, access to credit, and off-farm income affect AIM significantly. Farmers who have AIM are more likely to adopt LLL. Further, farmers who have AIM and have adopted LLL are more efficient compared to non-adopters and those non-affiliated with AIM. Our findings support the hypothesis that promoting agricultural institutions and enhancing farmer participation in AIM can facilitate technology dissemination, improve efficiency in production and farmer welfare.

This research is supported by ACIAR and Australia Awards.

15: A maize field. Photo: CIMMYT.

Essays on the economics of soil quality: Adoption and willingness to accept for land restoration and conservation program in Punjab Pakistan

Project team: Asjad Tariq Sheikh[1] (project leader: 22453495@student.uwa.edu.au), Dr Ram Pandit[1], Dr Amin Mugera[1], Dr Michael Burton[1], Dr Stephen Davies[2]

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

Punjab is considered the breadbasket of Pakistan. However, the province has experienced an increase in food demand due to rapid population growth and this has put pressure on the available arable land for food production. The situation is exacerbated by fragmented land and increasing cropping intensity that increases the demand for irrigation water leading to over-exploitation of groundwater. Inadequate investment and low adoption rate of soil conservation and restoration practices pose serious environmental problems that lead to poor soil quality and threatens the sustainability of agriculture. About one-fourth of all the irrigated area is affected by soil salinisation, mainly caused by overexploitation of groundwater.

Despite this, there is a lack of empirical evidence of the extent to which soil quality affects crop productivity and key factors that influence the adoption (or dis-adoption) of soil restoration practices in salt-affected areas of Punjab. The government of Pakistan has made efforts to restore salt-affected areas but the adoption of land restoration practices has remained low. There is a need to develop an integrated approach to tackle the source of secondary salinisation as well as to reverse salt-affected soil through designing a land restoration program where farmers' preferences for the design elements of a restoration program will be given high priority so that the government can enhance participation rate.

A farm household survey was conducted in 2019 to provide a quantitative basis to identify and address urgent economic policy priorities pertaining to land degradation, especially soil salinisation. The survey sample covered 504 farm households in 24 primary sampling units in rural areas of three districts representing three agro-climatic zones of Punjab namely: (i) Rice-Wheat Zone (Hafizabad district); (ii) Mixed Zone (Jhang district); and (iii) Cotton-Wheat Zone (Bahawalnagar district). Data was collected using a structured questionnaire from households who had cultivated agricultural plots during the 2018-19 production seasons. Aside from this, soil samples were collected from farmers' eligible plots (646) at the depth of 30cm and were analysed from the University of Agriculture, Faisalabad. Soil samples were analysed for six attributes including soil pH, electrical conductivity, ammonium, phosphorous, potassium, and organic matter.

In 2020, the data was analysed to construct a robust measure of soil quality (SQ) that combines diverse field-level soil-quality attributes and crop production data using a mathematical programming approach. We found variation in SQ based on wheat and rice crop production across different cropping zones. In addition, the study found that SQ is sensitive to soil electrical conductivity, which can be improved by application of gypsum. The adoption of gypsum can be accelerated through improved information delivery mechanisms through extension services.

This research is supported by the IFPRI and UWA.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16: Wheat field in Punjab, Pakistan.

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Farmers' perceptions of risk, management strategies and willingness to pay for crop insurance in Nepal

Project team: Bibek Sapkota[1], Associate Professor Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Associate Professor Michael Burton[1], Associate Professor Roy Murray-Prior[3]

Collaborating organisations: [1]UWA; [3]University of the Philippines Mindanao; NARC; ACIAR

Realising the need of assisting smallholder farmers in managing farming risks, the Government of Nepal has been implementing Agriculture Insurance (AI) program since 2013 through a public-private-partnership model. However, despite a 75 per cent subsidy in the premium, the adoption of crop insurance is negligible thus far. The design of existing AI program mainly draws on a feasibility study conducted by the World Bank, which only addressed supply side issues and implementation mechanisms. No research has ever looked at demand side issues such as farmers' risk perceptions, risk attitude and willingness to pay for risk management products in the Nepali context. This study tries to fulfil such an information gap focusing on these issues.

This research comprises four key areas following a mixed-methods research design involving both qualitative and quantitative methods, including Psychometric Scaling, Lottery-Choice Experiment (LCE) and Discrete Choice Experiment (DCE). Using qualitative research methods, we investigated farming risks, farmers' risk perception, attitude and existing risk management strategies. Using qualitative methods, we investigated farmers' risk perceptions, which were consistent with the findings in the qualitative research. We also investigated the effect of various factors on farmers' risk attitude and the effect of risk attitude on their risk management decisions. The fourth area of research was investigating the farmers' willingness to pay for crop insurance.

The research results have been presented and published in journal articles and a thesis. The findings will be useful for the government agencies to develop appropriate farming risk management policy and support programs, insurance companies to develop more saleable risk management products, and farmers to optimize their welfare making better farming and risk management decisions.

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

17: A farmer participating in a household survey.

18: A farmer making his choice in the lottery-choice experiment cards.

Prospects for participation of smallholder farmers in modern agribusiness value chains in Mindanao, Philippines

Project team: Jon Marx Sarmiento[1,2], Associate Professor Fay Rola-Rubzen[2] (project leader; fay.rola-rubzen@uwa.edu.au), Associate Professor James Fogarty[2], Professor Larry Digal[1]

Collaborating organisations: [1]University of the Philippines Mindanao; [2]UWA; [3]University of Sydney

The fruit-export industry provides livelihoods to millions of Filipino farmers and has the potential to promote inclusive rural development in Mindanao, Philippines. However, there is a limited body of knowledge in this area, especially around the production performance of smallholders and their capacity to access modern markets through contract farming arrangements. Hence, this research provides evidence on the prospect of smallholder high-value market participation in the fruit-export industry in Mindanao.

This research aims to assess the potential of an inclusive agribusiness value chain as a strategy for rural development. The following are the specific research objectives:

- Determine the performance of the Philippine tropical fruit industry in export markets
- Measure the capacity of smallholder farmers to participate in modern agribusiness value chains
- Assess the production performance of smallholder farmers supplying in modern markets, and
- Outline strategies to increase the participation of smallholder farmers in modern agribusiness value chains.

We calculated the annual comparative advantage performance of the Philippine tropical fruit exports during the last 20 years, 1997-2016. Findings reveal that the Philippines had a comparative advantage in exporting bananas, prepared and preserved pineapples, fresh and dried pineapples, pineapple juice, and prepared and preserved mixed fruits. We also constructed an index using a composite indicator approach and applied the index to a sample of 292 banana and mango farmers in northern and southern Mindanao. Farmers who were participating in modern markets had significantly higher livelihood capitals and index value compared to those participating in traditional markets. Using a random sample of 186 farmers in Davao del Norte, we applied a propensity score matching approach and employed both Data Envelopment Analysis (DEA) and Stochastic Frontier Production (SFP) function in calculating the technical efficiency (TE) among matched samples. We then applied truncated regression with bootstrapping to model the sources of efficiency for DEA and compared it with SFP. The results, which are robust across TE models and matching methods, reveal a significantly higher technical efficiency performance among individual and cooperative contract farmers compared with non-contract farmers.

This thesis provides a better understanding of modern market participation through individual and cooperative contract farming approaches. The latter approach is less explored in the literature. This research designs an index to measure farmers' capability to participate in modern value chains. The index has a practical contribution as it can be used by government and development workers to assess the capacity of farmers and farmers groups to participate in modern markets.

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

19: Smallholder Cavendish banana farms in Davao del Norte, Philippines.

20: Harvesting Cavendish bananas in Davao del Norte, Philippines.

Overseas labour migration: Its determinants and impacts on smallholder farm-households in Nepal

Project team: Associate Professor Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Dr Ram Pandit[1], Dinesh Babu Thapa Magar[1,2]

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

This study is aimed at understanding the migration-remittance-agricultural development nexus and reintegration of return migrants in Nepal. More precisely, this study has the objectives of assessing the determinants of migration decisions and destination choices, analysing overseas and return migration impacts on various agricultural outcomes including productive investments, and assessing occupational choice of return migrants.

Fieldwork and data collection for this study has been accomplished in two purposively selected districts; one representing the Terai plain and another representing the hill agro-ecology of Nepal. Primary data have been collected from 708 households (that includes 242 current overseas migrant, 267 returnee migrant and 198 non-migrant households) through household surveys including focus group discussions. Data entry, cleaning and analysis is currently taking place applying econometric tools and techniques.

The study findings are expected to enrich the understanding of the migration-remittance-agriculture dynamics as well as contribute in developing appropriate strategies for maximising the development impact of migration in Nepal.

This research is supported by the UWA SIRF Scholarship, Safety-net Top-up Scholarship and Postgraduate Award.

21: Interviewing a return migrant in Kaski district, Nepal.

22: Focus group discussions with farmers in Kaski district, Nepal.

Food safety in Vietnam: Perceptions, behaviours, economics and policy

Project team: Hue T Vuong[1] (project leader; 22214168@student.uwa.edu.au), Professor David Pannell[1], Associate Professor Steven Schilizzi[1], Associate Professor Michael Burton[1]

Collaborating organisation: [1]UWA

Food safety is an issue of growing concern in many developing countries, where policies regulating food safety and their enforcement still have many limitations. In Vietnam, a public survey carried out in 2016 found that the majority of consumers (87 per cent) are very concerned about the safety of food they consumed. Threats to food safety in Vietnam include contamination with toxic chemicals, microbiological contamination, and adulterated food. The Vietnamese government has tried various strategies to address this matter, but with limited success so far.

This study aims to contribute to improve food safety for vegetables and pork meat, which are two indispensable food items in Vietnam. The key objectives of this research are to investigate the relationship between perceptions and food-safety-related behaviours of vegetable producers and pork meat processors in Vietnam; and to analyse the benefits in monetary-equivalent terms for Vietnamese consumers from improved food safety for pork and vegetables. This thesis relies on primary data. The data was collected from three field surveys with the participation of 319 vegetable farmers, 278 pork processors and 314 consumers. These surveys were performed in three provinces (Hanoi, Hung Yen and Haiphong) in the Red River Delta, Vietnam, from October 2018 to January 2019. This research is important because it will fill in the knowledge gaps in perceptions, behaviour, economics and policies related to food safety in Vietnam. In addition, it will address issues from different parts of the production – processing – consumption food chain. Together, the results of this study will assist in providing critical insights for the design of more effective food-safety policies in Vietnam.

This research is supported by UWA.

23: A farmer tends to his field in Vietnam.

Effect of choice of marketing channels on quantity sold, price and revenue among maize-legume producers in Kenya: Application of a conditional logit model

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

Collaborating organisation: [1]UWA

Smallholder farmers are key actors in cereal markets in Sub-Saharan Africa (SSA). However, the existence of such markets and their effectiveness is not certain in many SSA countries. Consequently, understanding the factors affecting farm households' choice of marketing channel and its effect on quantities supplied, prices and revenues is important to facilitate the identification of potential ways to raise households' welfare. Thus, using panel survey data, this study evaluated the determinants of market channel choice for farm output in Western and Eastern Kenya. The market channels considered are other household consumers, village assembler or village trader. Transaction locations included farm gate, village market and urban market.

This study also evaluated the impact of choice of market channel on quantity sold, price and revenue received. Key determinants of choice of market channel include transaction cost, social ties, household size, age of household head, farm household wealth, output produced and time lag between harvest and sells. Quantities sold, selling price and revenue significantly differ across market channels. This outcome suggests policies aimed at reducing transaction costs, promoting and supporting collective maize marketing, strengthen rural institutions that promote social networks and developing strategies that promote increase in productivity through programs such as input subsidy could enhance market access and better integrate smallholder farmers into grain markets and improve their welfare.

This research is supported by The John Allwright Fellowship through ACIAR.

24: A fresh food market in Kenya.

Determinants and extent of market participation among maize-legume smallholders

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

Collaborating organisation: [1]UWA

Market participation is often considered as a crucial path towards improving living standards among subsistence farmers in developing countries. Yet, in such countries, smallholders are partially integrated into markets that are notably imperfect, where some sell surplus output, others have output deficits and are net buyers, while some are self-sufficient in production. However, relatively little is known about factors that contribute to farmers becoming deficit producers, surplus producers and autarkic and to what extent they participate in terms of quantities bought or quantities sold.

Using three waves of household surveys from Kenya between 2011 and 2015, this project applied a double hurdle model to evaluate determinants of whether to trade maize and legumes or not either as buyer or seller, or no trade at all. The study investigated the quantity traded conditional on market participation as a buyer or a seller. The study also investigated households' perception on the effect of production shocks on market participation. The control function approach and correlated random effects procedure were used to control for potential endogeneity of covariates and unobserved heterogeneity. Results shows that smallholders' perception on production shocks, particularly disease infestation and waterlogging, to be key determinants of sells decision and quantities sold. Likewise, seed quantity, wealth endowment and demographic factors determine both sells decision and extent. Both buying and selling decisions are influenced by farm location, transaction cost, maize and bean output prices and quantities harvested. The findings of this study have policy implications on how to integrate smallholder maize and legume producers into markets as a means of improving their welfare.

This research is supported by The John Allwright Fellowship through ACIAR.

25: Sacks of dried beans and maize at an African market.

Collective action for sustainable development: The case of smallholder dairy cooperatives in developing countries

Project team: Dr Amin Mugera[1] (project leader; amin.mugera@uwa.edu.au), Emeritus Professor Graeme Martin[1], Associate Professor Fay Roy-Ruben[1], Professor John Tarlton[2], Professor George Gitau[3], Professor Frederick Obese[4], Professor Liveliness Jessica Banda[5], Dr Bettie Kawonga[5], Ambrose Kipregon[3], Raphael Ayizanga[4]

Collaborating organisations: [1]UWA; [2]University of Bristol, UK; [3]University of Nairobi, Africa; [4]University of Ghana, Africa; [5]LUANAR

This project aimed to develop a data collection protocol for benchmarking and evaluating the performance of smallholder dairy cooperatives in developing countries. These cooperatives are critical for achieving the intertwined United Nations' Sustainable Development Goals (UN SDGs) and the Australian Centre for International Agricultural Research (ACIAR) goals of no poverty, zero hunger, gender equity, good health, and wellbeing. The high-quality data can be used to identify best management practices and barriers to optimal operation. The tool can be used for designing policies and management practices to improve the performance of cooperatives and enhance the welfare of people and animals at the farm, cooperative, and national level.

One workshop and fieldwork were held in Nairobi, Kenya, to collect data from smallholder dairy cooperatives/associations and dairy farmers. Under the leadership of Professor Goerge Gitau from the University of Nairobi, the fieldwork in Kenya was conducted from February 11-17 in 2020 to collect data from two dairy cooperatives and 30 dairy farmers affiliated to the cooperatives. This was followed by two days workshop held at University of Nairobi on February 19 and 20 . The workshop was attended by all the project members from Australia, UK, Ghana, Malawi and Kenya.

This project was successful in linking and facilitating three early career researchers from Malawi, Ghana, and Kenya to jointly conduct fieldwork in the respective countries, analyse the data under the guidance of the principal investigators and prepare field reports and oral presentations to achieve the project's objectives. The project was completed in 2020 and was successful in applying and getting a grant from the UK British Council to expand the project to investigate the potential impact of climate change in the smallholder dairy industry in sub-Saharan Africa. This new project will commence in March 2021.

This research is supported by the Australia Africa University Networks and the Worldwide University Networks.

26: The research team at the University of Nairobi.

The roles of adoption and behaviour change in agricultural policy

Project team: Professor David Pannell[1] (project leader; david.pannell@uwa.edu.au), Dr Roger Claassen[2]

Collaborating organisations: [1]UWA; [2]US Department of Agriculture

Much of agricultural and agri-environmental policy is concerned with influencing the behaviour of farmers in adopting new practices. An ability to understand and predict adoption of practices is useful for agricultural policy in several ways, including assessing additionality, selecting policy mechanisms, targeting policy to practices, farmer types or regions, and assessing likely policy success. Clear thinking about adoption is sometimes clouded by ambiguous and inconsistent language.

In this research, we suggest a number of terms that are more specific than "adoption". Research needs include collection of long-term data sets on adoption of a variety of practices, understanding what determines continuous, sustained adoption of conservation practices and a better understanding of why adoption varies between farms.

Information about the adoption of new practices in agriculture is important in agricultural policy for a range of purposes. Research literature focused on the topic is very large, but is not always consulted by agricultural policymakers, perhaps in part because relatively little effort has been taken to synthesise results in forms that are particularly useful to policy makers. Some basic and well-established insights from the adoption literature, if better and more widely utilised in policy, could make substantial contributions to the delivery of benefits to the agricultural sector and the broader community. Adoption is also at the heart of some challenging and conceptually difficult issues, such as additionality and policy mechanism choice. We hope that the insights from this research can assist policymakers and policy advisors to consider agricultural adoption in a more sophisticated and nuanced way, leading to better policy outcomes.

This research is supported by the US Department of Agriculture Economic Research Service.

27: A crop of corn planted without tillage. This research notes that many farmers around the world have adopted zero-till farming, even in the absence of program incentives.

Agriculture adoption and behavioural economics: Bridging the gap

Project team: Nadia Streletskaya[1] (project leader; nadia.streletskaya@oregonstate.edu), Dr Samuel Bell[1], Dr Tongzhe Li[2], Simanti Banerjee[3], Dr Leah Palm-Forster[4], Dr Maik Kecinski[4], Professor David Pannell[5]

Collaborating organisations: [1]Oregan State University, US; [2]University of Guelph, Canada; [3]University of Nebraska-Lincoln, US; [4]University of Delaware, US; [5]UWA

This research provides a brief, selective review of the linkages and complementarities between agriculture adoption and behavioural economics, highlighting three themes that have potential for future research. While we have focused on models and topics of interest, highlighting some of the emerging literature in the field, both disciplines would also benefit from a wider cross-pollination of methods, such as the use of large-scale observational data in behavioural economics research, and the wider use of experiments in the adoption literature. In order to provide policymakers with relevant and robust evidence on agricultural adoption, experimental methods could be employed at the farm-level. Along the same lines, behavioural economists could capitalise on the opportunity to validate behavioural models with farmers given their strong social identity, non-trivial stakes in decision-making and central role as land managers in environmental, social and health outcomes.

The intersection of behavioural economics and agricultural adoption research can provide valuable insights into farmer behaviour, may validate underlying behavioural models or call for improvements in the existing frameworks. The three thematic areas selected in this paper are not to be seen as exhaustive, but merely present a few examples in a myriad of other potential subject areas where behavioural economics and agricultural adoption can inform one another. Hence, the linkages and indicative opportunities detailed here are meant to provide a launching point for further research that advances research in both the behavioural economics and agricultural adoption fields.

28: Gaining a more thorough understanding of how farmers make decisions under ambiguous risks of climate change and extreme weather events is urgently needed.

Science, technology and innovation for Sustainable Development Goals: Insights from agriculture, health, environment and energy

Project team: Dr Ademola Adenle[1] (project leader; adenle@unu.edu), Professor Marian Chertow[2], Professor Ellen Moors[3], Professor David Pannell[4]

Collaborating organisations: [1]Africa Sustainability Innovation Academy; [2]Yale University, US; [3]Utrecht University, The Netherlands; [4]UWA; Australian National University; Centre for Global Health Security, UK; International Rural Poultry Centre, Australia; University of Witwatersrand, South Africa; University of Glasgow, UK; Nacional Universidade de Timor Lorosa'e, Timor Leste; University of Greenwich, UK; The University of Sydney; Wageningen University, The Netherlands; Australian Centre for International Agricultural Research; Maastricht University, The Netherlands; Interdisciplinary Center Herzliya, Israel; University of Buenos Aires, Argentina; Leibniz Institute DSMZ, Germany; International Livestock Research Institute, Kenya; University of New England, Australia; Lebanon Valley College, US; Cornell University, US; FIOCRUZ, Brazil; Westmead Hospital, Australia; CIAT; Federal University of Rio de Janeiro, Brazil; Ben- Gurion University of the Negev, Israel; IRLI; German Development Institute; University of Delaware, US; ETH Zurich, Switzerland; Ghent University, Belgium; Providence College, US; World Bank, US; IFAD; LCA consultants; Xi'an Jiaotong, China; Liverpool University, UK

After the United Nations adopted the 17 Sustainable Development Goals (SDGs) to "end poverty, protect the planet, and ensure prosperity for all," researchers and policy makers highlighted the importance of targeted investment in science, technology, and innovation (STI) to make tangible progress. Science, Technology, and Innovation for Sustainable Development Goals showcases the roles that STI solutions can play in meeting on-the-ground socio-economic and environmental challenges among domestic and international organisations concerned with the SDGs in three overlapping areas: agriculture, health, and environment/energy.

Authors and researchers from 31 countries tackle both big-picture questions, such as scaling up the adoption and diffusion of new sustainable technologies, and specific, localised case studies, focusing on developing and middle-income countries and specific STI solutions and policies. Issues addressed include renewable energy, automated vehicles, vaccines, digital health, agricultural biotechnology, and precision agriculture. In bringing together diverse voices from both policy and academic spheres, this volume provides practical and relevant insights and advice to support policy makers and managers seeking to enhance the roles of STI in sustainable development.

- Key reference work for applying STI solutions and policies towards national and international SDGs
- Highlights findings across the natural and social sciences from leading researchers representing over 40 institutions and more than 30 developed and developing countries around the world
- Offers specific guidelines for implementing STI practices towards meeting SDGs across environmental, health, and agricultural sectors through ample case studies and examples, and
- Provides answers for how to integrate various stakeholder views on STI solutions that support accountability and transparency in decision-making in developing countries.

29: The United Nations' 17 Sustainable Development Goals.

30: An example of precision agriculture in the field.

7

Education and Outreach Activities

Strengthening communication links with industry, farmer groups and the broader regional and scientific communities is one of IOA's key strategies. A number of communication channels are used to ensure the University's research in agriculture and related areas is shared with its intended audience. IOA plays an active role in listening to growers, advisors and agribusiness professionals, to ensure two-way communication and that all ideas and perspectives are considered in the identification of key issues and opportunities.

Newsletters

IOA's broad range of activities are regularly captured through its newsletter. It is an important channel through which IOA promotes its research outcomes, collaborations, staff and student achievements and upcoming events to key stakeholders, alumni, the agriculture industry, funding bodies and UWA staff.

The newsletter serves as a record of IOA's research activities and captures newly funded research projects, new staff and students, visitors and, importantly, a list of new peer-reviewed journals in agriculture and related areas.

Published three times per year – in April, August and December – the newsletter is circulated widely to more than six thousand readers.

Online Presence

IOA launched a new website www.uwa.edu.au/ioa in September. The new-look website provides an overview of IOA's 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 current Strategic Plan, Annual Research Report and newsletters are also readily available to view and download.

In August, IOA launched new LinkedIn and YouTube social media accounts. The seven videos published to YouTube in 2020 amassed more than 1,400 views, and about 160 people began following the official LinkedIn page. The @IOA_UWA Twitter presence continued to grow, ending the year with approximately 1,300 followers.

Visitors

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. However, IOA was fortunate to host international students who arrived at the start of the year or with travel exemptions, including seven undergraduate students from South China Agriculture University, two PhD students from University of California, Berkeley and Dr Georgget Banchero Hunzicker from the National Institute of Agricultural Research in Uruguay. Local visitors, including three Shenton College Year 10 students on work placement, 24 members of the 1970 UWA graduating class in agriculture and lecturer Dr Graeme Robertson visited in the second half of 2020. IOA and the UWA SAgE also hosted a Networking Workshop for postgraduate students in agriculture and related areas in September.

Shortly after his arrival in July, UWA Vice-Chancellor Professor Amit Chakma met IOA team members at a special morning tea at Bayliss Foyer. Professor Chakma also joined the IOA IAB meeting in September and opened the 2020 Industry Forum.

IOA held a full-day workshop in August to finalise its *Strategic Plan 2021-2025*. The event was attended by key leaders from UWA and the agriculture industry, including UWA DVCR Professor Tim Colmer, former UWA VC Emeritus Professor Alan Robson, UWA Oceans Institute Director Associate Professor Julian Partridge and IAB Chair Dr Terry Enright.

Meetings, lectures and seminars frequently took place online, with IOA hosting two webinars and its researchers participating in dozens of online events throughout the year. These online interactions were critical to knowledge sharing and strengthening research links and collaborations.

1: IOA team morning tea with the UWA Vice-Chancellor Professor Amit Chakma.

2: Shenton College Year 10 students (seated) with members of IOA.

3: Postgraduate students at the Networking Workshop.

4: Participants in a workshop to finalise the IOA *Strategic Plan 2021-2025*.

GRDC Grains Research Update

The 2020 GRDC Grains Research Update Perth was held on 24-25 February.

The two-day program included more than 50 presenters sharing their latest research results and innovations to assist on-farm production and profitability.

Four UWA students were awarded funding from GIWA to attend the event, including Justina Serrano, Martina Badano, Julian van der Zanden, and Harmanpreet Kaur.

These scholarships provide opportunities for students to advance their understanding of the latest grains research and development, and to network with local and international researchers, agribusinesses and farmers.

UWA researchers presented their latest research and developments at the event, including:

- Dr Andrew Guzzomi, School of Engineering and IOA: *The Weed Chipper - mechanical site-specific fallow weed control*
- Daniel Kidd, UWA SAgE: *Impacts of liming and pasture rotations on wheat yield in the row rainfall zone*
- Professor Hugh Beckie and Mechelle Owen, AHRI: *Updates on Herbicide resistance in the WA grainbelt and future management challenges*
- Peter Newman, AHRI: *The continuing evolution of Harvest Weed Seed and Chaff systems*
- Dr Roberto Busi, AHRI: *What do we know of new herbicides of annual rye grass and wild radish control?*
- Facundo Cortese and Roberto Lujan, AHRI: *Pre-emergence herbicides and crop competition for effective management of annual ryegrass*
- Huan Lu, AHRI: *Hydroxyphenylpyruvate dioxygenase (HPPD) resistance in wild radish*

In his presentation, Dr Guzzomi announced that the Weed Chipper design would be commercialised and offered to Australian farmers by Precision Agronomics Australia.

He said that commercialisation of the research was a significant development for Australian grain growers and the grains industry in general, as it allowed for a reduced reliance on herbicides.

5: Aniruddha Maity, Sandra Mata, Justina Serrano, and Manjula Premaratne at the GRDC Grains Research Update.

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Postgraduate Showcase: Frontiers in Agriculture

Top postgraduate students presented their latest research in agriculture and related areas at IOA's 14th annual Postgraduate Showcase on 30 September.

UWA SAgE Senior Research Officer Daniel Kidd presented his PhD research on improving phosphorus efficiency of pastures in southern Australia.

"We want to reduce the use of fertiliser in our cropping and pasture systems because overuse has a negative effect on our environment and waterways," Dr Kidd said.

School of Molecular Sciences PhD student Kirill Sukhoverkov then presented on his research into predicting new herbicides from phys-chem parameters.

"The rise of herbicide resistance in recent decades has put the global food security under serious threat," Mr Sukhoverkov said.

"Therefore, finding novel modes of action of herbicides is a fascinating challenge."

Jorge Silva's project was to develop a low-cost portable spectral imaging system to detect faecal matter on chickens as part of PhD research in the School of Engineering and Mechanical Sciences.

UWA SAgE PhD student Maria Purnamasari's research analysed how plant defence mechanisms were compromised when plants are left under shade.

"Just like humans, plants that don't get enough sun are more susceptible to disease and pathogens," Ms Purnamasari said.

Shamshad Ul Hassan's UWA SAgE PhD research looked into understanding diarrhoea and worm resistance in sheep through gene expression.

"Animal health and wellbeing is one of my greatest priorities, and that is why my research focus is to rectify these issues," Mr Hassan said.

UWA SAgE PhD candidate Mohammad Golam Kibria's project explored how foliar magnesium application enhances wheat growth in acidic soil.

Hui Cao from the School of Molecular Sciences looked at why making proteins fast could help modern wheat agriculture.

"As I grew up in a farm family, the dream of helping farmers yield more with less costs has guided me to this path," Mr Cao said.

Electronics and Computer Engineering student Omar Anwar said his research combined technology and agriculture to develop low-cost, low-power and long-range remote beehive health monitoring solutions.

"Using new technologies, we will be able to take better care of bees and enhance our future food supply," Mr Anwar said.

6: Presenters and contributors to the 2020 Postgraduate Showcase: Frontiers in Agriculture.

7: Audience members watching postgraduate students present at the Ross Lecture Theatre, UWA.

Industry Forum

Climate change and agriculture: Challenges and solutions for Australian farmers

Tackling the many challenges of climate change had everyone talking at IOA's 14th annual Industry Forum at the University Club of Western Australia Auditorium on 28 October.

In his opening address, UWA Vice-Chancellor Professor Amit Chakma told the audience: "I am a strong supporter of IOA because of what it has done over the years, and what it will continue to do."

Hackett Professor Kadambot Siddique then introduced IOA's IAB Chair Terry Enright, who served as Master of Ceremonies.

Delivering his keynote address via video from Canberra, Australian National University Climate Change Institute research fellow Steven Crimp said climate change was a significant challenge to agricultural production.

Dr Crimp referred to long-term climate forecasts which showed that temperatures in Australia could rise by 4.5 degrees by 2090 and – for every addition degree – WA's rainfall could decline between four and seven per cent.

UWA Professor Phil Vercoe then took to the stage to discuss the potential of capturing methane energy from ruminants and use it for production.

Professor Vercoe also explored the role that various Australian native shrubs play in reducing methane.

CSIRO Senior Research Scientist Dr Yvette Oliver presented on ways to increase the ability of soils to hold and capture water, reduce evaporation losses and achieve early crop vigour.

Australian Export Grains Innovation Centre chief economist and UWA Professor Ross Kingwell introduced the idea that droughts on the east coast of Australia could be seen as a commercial opportunity for WA.

DPIRD research officer Meredith Guthrie took the audience through data from the south-west WA land division that showed the shifts in climate since the mid-1970s.

The final two speakers were working farmers and UWA graduates Simon Wallwork and Dylan Hirsch.

2018 Nuffield Scholarship recipient Mr Hirsch detailed the ways he was mitigating drought risk on his farm in Latham.

"While our yields might not appear to be increasing, our water-use efficiency is slowly improving as we adopt better technologies and practises," he said.

Mr Wallwork, who was involved in the Climate Champion Program and jointly formed AgZero2030 in 2019, said his children inspired him to pursue carbon neutrality on his Corrigin farm.

The following sundowner brought agriculture industry leaders, stakeholders, researchers, students and farmers out into the courtyard to enjoy refreshments and continue the very important conversation.

8: Professor Phil Vercoe, Richard Hudson, UWA VC Professor Amit Chakma, Dylan Hirsch, Professor Ross Kingwell, Meredith Guthrie, Simon Wallwork, Dr Yvette Oliver, Hackett Professor Kadambot Siddique, and Dr Terry Enright.

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Mike Carroll Travelling Fellowship

During a time when international travel was grounded by COVID-19, it was especially rewarding to hear from three Mike Carroll Travelling Fellowship recipients at the 17th annual presentation evening on 12 November.

Twenty four UWA students have benefitted from the Fellowship since it was established in 2003 as a memorial to former Director General of the WA Department of Agriculture, the late Dr Mike Carroll, in recognition of his commitment to agriculture.

Following an introduction from IOA Director Hackett Professor Kadambot Siddique, Ms Helen Carroll introduced the 2020 Fellowship recipient Michael Young, who planned to visit the USA and Canada in 2021.

First to present was PhD student Suyog Subedi, who visited the University of Copenhagen in Denmark to research how African Mohogany could reduce worm load and improve gut health in livestock.

Although he planned to return home to his baby daughter after three months, the outbreak of the pandemic meant that he was stranded in Europe (and later his home country Nepal) for almost nine months.

Despite the significant changes to his plans, Mr Subedi achieved a great deal in the laboratory – forging partnerships and learning a new technique of harvesting parasite eggs that will save time, money and resources.

PhD student Yueqi Zhang spoke about her time at the Centre of Plant Structural and Functional Genomics in the Czech Republic to explore single chromosome isolation in canola in 2018.

Thanks to the generous Fellowship, Ms Zhang was fortunate to extend her stay from three to seven months. After many long hours and even staying awake overnight in the lab to record data every hour, she was able to achieve the highest chromosome yield in canola for the first time.

Finally, PhD student Soodeh Tirnaz discussed her time in Japan conducting research into diseases in canola and Japanese spinach.

Ms Tirnaz counted her greatest achievements during the fellowship to be learning new techniques, presenting her research to Kobe University and Graduate University for Advanced Studies (SOKENDAI), visiting other research groups and collaborating on publications.

9: Helen Carroll, Marie-Louise Carroll, Yueqi Zhang, Suyog Subedi, Soodeh Tirnaz and Hackett Professor Kadambot Siddique.

Hector and Andrew Stewart Memorial Lecture

While the impact of pandemic border closures have exposed weaknesses in our food production and imports, climate change continues to be the greatest challenge to food security in WA.

This was the overarching message Dr Graeme Robertson delivered at IOA's 27th Hector and Andrew Stewart Memorial Lecture on 17 November.

As WA's only Rhodes Scholar in agriculture and having served as the Director General of WA Department of Agriculture for a decade, Dr Robertson was well-positioned to present his lecture on the reality of food security and agriculture in WA.

Although WA exports significant amounts of grains and some meat, Dr Robertson cautioned that the State's production was a very small proportion of the world's food supply.

"We produce enough calories to feed about 10 million people, which is just 0.13 per cent of the world population," he said.

So how secure is our supply of food? According to Dr Robertson, you only need to walk down the supermarket aisles to see just how reliant we are on food being transported long distances to Perth, especially from eastern Australia.

"An important driver of the profitability of food retailing is the amount of stocks in the system," he said.

"This year we had two disruptions – bushfires closed the Eyre highway for 12 days in January and this began to affect supermarket supplies.

"COVID-19 also resulted in shortages or absence of some products as production facilities and distribution centres were affected."

In his lecture, Dr Robertson concluded that climate change was the greatest medium to long-term threat to WA's agricultural production.

10: Dr Graeme Robertson met with UWA PhD students for a special morning tea ahead of the lecture.

11: Hackett Professor Kadambot Siddique (left) with Dr Graeme Robertson (middle) and Stewart family and friends.

Future Farm 2050 Project: 2020 Highlights

The Future Farm 2050 Project (FF2050) 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.

Outreach

National and international restrictions due to the COVID-19 pandemic impacted the usually high number of visitors to UWA Farm Ridgefield.

The FF2050 team engaged with the wider community and agriculture industry by presenting at the 2020 GRDC Grains Research Update, AFI Farm Biodiversity Certification Scheme via Zoom and Wheatbelt NRM Talkin' Soils 2020: Building Natural Capital.

In January, seven students and two staff undertook a Chinese Study Tour. Two months later, Emeritus Professor Graeme Martin represented Pingelly and UWA Farm Ridgefield as a major regional engagement site at the UWA Regional Advisory Group (DVC Community Engagement). That same month, Senior Policy Adviser to the Office of the National Soils Advocate Sue Bestow visited the Critical Zone Observatory and Flux Tower at UWA Farm Ridgefield.

At the Yarra Yarra Land Management Day 'Living Haystack' at Perenjori in August, Catherine McKenna delivered a talk on UWA Farm Ridgefield achievements.

Our strong online presence allowed us to engage with people all around the world. Six international presentations were held on FF2050 Project throughout 2020. The Massive Open Online Course *Discover Best Practice Farming for a Sustainable 2050* attracted a further 15 thousand enrolments in 2020, reaching a total of 23,629 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.

Throughout the year, 20 media articles were published, six international presentations were given, and eight peer-reviewed research papers were published.

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. Although many planned visits and exchange students had to be cancelled due to the pandemic, seven class excursions went ahead in 2020.

Early in the year, 18 Japanese students from Tokyo University of Agriculture, a Chinese Study Tour was held with Catherine McKenna, and students from University of Veterinary Science in Myanmar visited UWA Farm Ridgefield with Professor Phil Vercoe.

More than 80 students attended a soil practicum field trip at UWA Farm Ridgefield with Dr Matthias Leopold in April. Additionally, 40 second-year undergraduate students studying Pasture & Livestock Systems visited Ridgefield for a field trip with Professor Megan Ryan, Professor Phil Vercoe, Associate Professor Dominique Blache and Professor Phil Nichols.

In August, a group of Curtin University Architecture students visit UWA Farm Ridgefield as part of a third-year project to design a rural education campus on the farm. That same month, UWA Aerospace club members, with approval from the Civil Aviation Safety Authority, launched a helium balloon at the farm. Central Griffith University International Water Course visited the farm in December.

The following month, about 60 members of the agricultural community, UWA postgraduate students and rangers from the Noongar Boodja Ranger program participated in a field day to demonstrate 'fast-track restoration' of soil on a field site on the western corner of the farm.

Five UWA postgraduate students conducted research at UWA Farm Ridgefield throughout the year, including Wesley Moss from the School of Mechanical and Chemical Engineering, Gabrielle Beca from the School of Biological Sciences, and UWA SAgE PhD candidates Hira Shaukat and Ahmed Alsharmani.

The following high school engagements occurred in 2020:

- Professor Shane Maloney hosted the *The Crop is Right* activity for about 120 Year 9 and 10 students during the ConocoPhillips Science Experience Program.
- FF2050 Project Officer Sandra Mata presented on the Geographical Association WA to 30 high school Geography teachers.
- Professor Vercoe included the UWA Farm Ridgefield in his presentation to 120 Carine Senior High School students.
- Emeritus Professor Martin presented to 2020 Year 12 Agriculture College students during a tour of UWA.
- Wesley College initiated discussions with Emeritus Professor Martin about presenting a course in the micro-credential on agribusiness.

Memberships and awards

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 UWA Farm Ridgefield), Terrestrial Ecosystems Research Network (flux towers are at Ridgefield and neighbouring Boyagin Reserve), and Animal Welfare Initiative.

The FF2050 Project is part of the Merino Lifetime Productivity Project (UWA Farm Ridgefield is one of five national sire evaluation sites), The Animal Welfare Collaborative, Australian Association of Animal Science and Pingelly Community Resource Centre.

The farm is also one of six MLA Producer Demonstration Sites for a four-year project demonstrating the impact of shifting to non-mulesing enterprises, run by UWA alumni Georgia Reid and Ed Riggall of AgPro Management.

In October, a Memorandum of Agreement was signed between IOA and The University of Yamaguchi (UY) in Japan. Consequently, Emeritus Professor Martin participated in a 'remote classroom' with UY veterinary students.

The FF2050 Project was nominated in the WA Regional Achievement and Community Awards. UWA Honorary Research Fellow Patrick Beale, who designed the Farm Manager's House on UWA Farm Ridgefield, won the 2020 WA Architecture Awards for designing the Pingelly Recreation and Cultural Centre (PRACC).

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Local community

The future of agriculture depends on people as well as technology, so the FF2050 Project includes the social sciences and health sciences.

UWA Adjunct Lecturer Dr Susan Bailey is forging links between UWA staff and the Pingelly community through the Pingelly Aboriginal Progress Association, Shire of Pingelly, and Pingelly Community Resource Centre. In October, UWA Farm Ridgefield hosted local aboriginal elders Gary and Gloria Bennell and three of their grandchildren for a local Indigenous culture exchange.

In March and August, UWA and IOA team members met with the Shire of Pingelly representatives and discussed plans for collaborating on the upcoming 2021 Pingelly Astrofest event.

Technological advancements

Agricultural Engineering activities continue to develop on the farm. In February and October, UWA School of Engineering's Dr Dilusha Silva visited with a group of Electronic Engineering Design undergraduate students. The students have been tasked with designing a deployment of Wi-Fi communications across key locations on the farm. Students have completed their designs and model, and deployment is expected in 2021.

Planning for the Telstra communications tower to be built on the farm continued in 2020. When completed in 2021, the tower will provide mobile phone coverage across the entire farm, while also enabling high-speed data connectivity to the outside world.

12: UWA Aerospace launched a high altitude balloon on UWA Farm Ridgefield.

13: UWA Dr Fran Hoyle, Sue Bestow, Dr Matthias Leopold, and Emeritus Professor Graeme Martin in front of the Ridgefield OzFlux Flux Tower.

14: Hackett Professor Kadambot Siddique and Business Manager Diana Boykett (pictured with Farm Manager Richard McKenna) visited the farm in August.

15: UWA Electronic Engineering Design undergraduate students visiting UWA Farm Ridgefield.

Media Statements

The Institute continued communicating its research outcomes to the general public through the media by distributing media statements in agriculture and related areas throughout 2020. A commendable amount of media coverage was generated in local, rural, national and international print, broadcast and online media.

Date	Title
19 February	New technology to speed up the development of more resilient crops
24 February	Australian farmers to reap rewards from weed chipper
5 March	Genetic diversity improves yields in hybrid varieties
9 April	The UWA Institute of Agriculture April newsletter
20 April	Ensuring global food security during COVID-19
21 May	Scientific debate over peanut origin laid to rest
18 June	First crop of PhD students arrive from Japan
25 June	How local knowledge and IP contributes to agricultural innovation
7 July	The UWA Institute of Agriculture releases Annual Research Report 2019
14 July	Smart scholarship explores Smart Weed management technology
16 July	Soil health key to sustainable agriculture
5 August	UWA-MLA BeefLinks partnership to boost red meat industry
10 August	The UWA Institute of Agriculture August newsletter
25 August	Biochar and zinc application can improve wheat grown in certain soils
8 September	Hostile fungus found to protect against cereal diseases
15 September	Scientists solve 70-year old mystery of the origins of oat disease
25 September	Students showcase the future of agriculture
7 October	Gene search aims to combat heat stress in canola
10 November	The University Of Western Australia joins Australia India Water Centre
19 November	UWA celebrates 12 researchers on Highly Cited Researchers 2020 list
23 November	Five UWA projects receive $2.5 million in national research funding
26 November	Landmark study to improve global wheat production
3 December	Using black soldier fly technology to dispose of agricultural waste
14 December	The UWA Institute of Agriculture December newsletter

Public Lectures and Special Seminars

Date	Presenter/s	Organisation	Title
30 July	Adj Prof Helen Spafford	Senior Research Scientist at the WA Department of Primary Industries and Regional Development	The challenge of managing fall armyworm: a new cross-industry pest in WA
27 October	Prof Anu Rammohan Dr Ashok Singh Adj Prof Rajeev Varshney H/Prof Kadambot Siddique	UWA Indian Agricultural Research Institute (IARI) International Crops Research Institute for the Semi-arid Tropics (ICRISAT) UWA IOA	India Week at UWA: Challenges and Opportunities for Indian agriculture
17 November	Dr Graeme Robertson	Former Director General of Agriculture	Hector and Andrew Stewart Memorial Lecture: Food Security and Agriculture in Western Australia

Awards and Industry Recognition

Name	Award
H/Prof Kadambot Siddique	Visiting Professorship from Amity University, India
Ms Cassandra Howell	First place, Science category, 2019 AgriEducate Essay Competition
H/Prof Kadambot Siddique	Outstanding contributions in the field of agriculture, Kerala Agricultural University
Prof Stephen Powles	BASF industry recognition award
Prof Harvey Millar	ARC Laureate Fellowship
Mr Patrick Beale	George Temple Poole Award for the Pingelly Recreation and Cultural Centre
Ms Mia Kontoolas	Calenup Postgraduate Research Fund Scholarship
Mr Michael Young	Mike Carroll Travelling Fellowship 2020
Adjunct Prof Rajeev Varshney	Rafi Ahmed Kidwai Award
A/Prof Hank Greenway	Australian Society of Plant Scientists Teaching Award 2020
Dr David Turner	Australian Society of Plant Scientists Teaching Award 2020
Dr Jane Gibbs	Australian Society of Plant Scientists Teaching Award 2020
Dr Brian Atwell	Australian Society of Plant Scientists Teaching Award 2020
H/Prof Kadambot Siddique	Clarivate Highly Cited Researchers 2020
Em/Prof Hans Lambers	Clarivate Highly Cited Researchers 2020
Prof Harvey Millar	Clarivate Highly Cited Researchers 2020
Prof Davey Jones	Clarivate Highly Cited Researchers 2020
Prof Dave Edwards	Clarivate Highly Cited Researchers 2020
Prof Ryan Lister	Clarivate Highly Cited Researchers 2020
Adj Prof Rajeev Varshney	Clarivate Highly Cited Researchers 2020
Dr Karen Frick	Functional Plant Biology Best Paper Award for 2019: The Australian Society for Plant Scientists
Adj Prof Ashwani Pareek	Tata Innovation Fellowship 2020: Department of Biotechnology, Government of India

New postgraduate research students

Name	Topic	School	Supervisor(s)	Funding body
Mr Tsubasa Kawai	Genetic and functional analysis of compensatory growth of lateral roots in rice	UWA School of Agriculture and Environment and IOA	H/Prof Kadambot Siddique, A/Prof Hirokazu Takahashi and Prof Yoshiaki Inukai (Nagoya University) and Dr Yinglong Chen	Joint PhD program
Mr Mukesh Choudhary	Genetics of heat tolerance in wheat	UWA School of Agriculture and Environment and IOA	Profs Wallace Cowling, Guijun Yan and H/Prof Kadambot Siddique	UWA International Fee Scholarship University Postgraduate Award (UPA)
Mr Sina Nouraei	Super genes and transcription factors associated with abiotic stress in wheat	UWA School of Agriculture and Environment and IOA	Prof Guijun Yan and Dr Helen Liu	Scholarship for International Research Fees UPA
Mr Aldrin Cantilla	Exploring the genetic potential in *Brassica napus* cultivars and its wild relatives for Blackleg resistance genes	School of Biological Sciences	Profs Jacqueline Batley, Wallace Cowling, Dave Edwards and Dr Philipp Bayer	GRDC
Agyeya Pratap	Revealing the role of G-proteins in heat and drought stress response in wheat	UWA School of Agriculture and Environment and IOA	H/Prof Kadambot Siddique and Dr Nicolas Taylor	Scholarship for International Research Fees UPA
Mr Md Shahin Iqbal	Mungbean salinity tolerance	UWA School of Agriculture and Environment and IOA	Prof William Erskine, Dr Lukacs Kotula and Adj A/Prof Imran Malik	ACIAR - John Allwright Fellow
Mr Mohammad Salim	Drought tolerance, root architecture and phosphorus levels of soybean	UWA School of Agriculture and Environment	Dr Zakaria Solaiman, Hackett Prof Kadambot Siddique and Dr Yinglong Chen	Bangabandhu Science and Technology Trust, Bangladesh Government
Mr Michael Young	Optimal sheep stocking rates for broadacre farm businesses in Western Australia	UWA School of Agriculture and Environment	Prof Phil Vercoe and Prof Ross Kingwell	DPIRD Sheep Industry Business Innovation Scholarship

New research grants awarded in 2020

Title	Funding period	Funding body	Investigators
A new Western Australian flavonoid-rich apple, Bravo™, and vascular health	2019-2020	Edith Cowan University ex Fruit West Co-Operative Ltd	Dr Kevin Croft
Increasing knowledge and profitability of cropping on Ironstone gravel soils	2019-2020	GRDC	Prof Daniel Murphy, Dr Frances Hoyle, A/Prof Peta Clode, Prof Andrew Whiteley, Dr Matthias Leopold, A/Prof Martin Saunders, Dr Andrew Rate, Dr Talitha Santini, Prof David Jones, Prof Matthew Kilburn
Soil sulfur influence on microorganisms	2019-2020	DPIRD	Dr Deirdre Gleeson
Proof of concept for Flash Farming and Benchmarking	2019-2021	DPIRD	Prof Philip Vercoe and Dr Zorica Durmic
Managing flies for crop pollination	2018-2020	DPIRD ex Horticulture Innovation Australia	Dr David Cook, Dr Romina Rader, Prof James Cook, Dr Rakhesh Nisha, Dr Sasha Voss, A/Prof Markus Riegler, Dr Jonathan Finch, Dr Cameron Spurr and E/Prof Lynette Abbott

Title	Funding period	Funding body	Investigators
Who's who in the plant gene world?	2020-2022	ARC Discovery Project	Prof Dave Edwards and Prof Jacqueline Batley
Deciphering organelle transport mechanisms in plants	2020-2022	ARC Discovery Project	Dr Monika Murcha, Assoc/Prof Joshua Heazlewood, Prof Alison Baker
Benefits and costs of non-market valuation for environmental management	2020-2022	ARC Discovery Project	Prof David Pannell, Dr Abbie Rogers, Assoc/ Prof Michael Burton, Mr MD Sayed Iftekhar and Prof Robert Johnston
Facilitation of high leaf phosphorus-use efficiency by nitrate restraint	2020-2022	ARC Discovery Project	E/Prof Hans Lambers, Dr Patrick Finnegan and A/Prof Maheshi Dassanayake
Collective action for sustainable development: The case of smallholder dairy cooperatives in ODA countries	2019	Australia Africa Universities Network	Dr Amin Mugera, Prof George Gitau, Prof Frederick Obese and Prof John Tarlton
Rapid breeding for reduced cooking time and enhanced nutritional quality in common beans (*Phaseolous vulgaris*)	2019-2023	ACIAR	Prof Wallace Cowling and H/Prof Kadambot Siddique
Closing the loop, Black Soldier Fly technology to convert agricultural waste into high quality fertiliser and soil improvers from DAWR	2019-2022	Australian Pork Ltd ex R&D4P	Dr Sasha Jenkins, Dr Martit Kragt, Assoc/Prof Megan Ryan, Dr Andrew Guzzomi, Dr Fiona Dempster, Prof Phil Vercoe, I Waite, Mr Daniel Kidd, Dr Tabitha Santini, H/Prof Kadambot Siddique and E/Prof Lyn Abbott
Enhancing the understanding of the value provided to fisheries by man-made aquatic structures	2019	Curtin University Ex Fisheries Research and Development Corporation FRDC	Assoc/Prof Michael Burton and Dr Julian Clifton
Functional genomics of chickpea to enhance drought tolerance	2019-2021	DIIRS, AISRF Indo-Australian Biotechnology Fund	Prof Harvey Miller, Prof Dave Edwards and H/Prof Kadambot Siddique
Essays on the economics of soil quality: Agriculture productivity, adoption (or dis-adoption) and willingness to pay for land restoration schemes in Pakistan's Punjab	2019	International Food Policy Research Institute IFPRI	Ass/Prof Ram Pandit, Dr Amin Mugera and Mr Asjad Sheikh
BeefLinks Program	2019-2022	MLA Donor Company	Prof Philip Vercoe
Smart Farms Small Grants Round 2 - Farm demonstration to fast-track restoration of soil condition using pereable biomass barriers	2019	National Landcare Program	E/Prof Lynette Abbott, Dr Sasha Jenkins and Dr Zakaria Solaiman
Smart Farms Small Grants Round 2 - Engaging digital media to more effectively build confidence in use of sustainable land management practices	2019	National Landcare Program	E/Prof Lynette Abbott
Nexgen-UWA Herbicide Partnership	2019	Nexgen Plants	Dr Joshua Mylne, Dr Keith Stubbs and Dr Joel Haywood
Program 2 - Towards effective control of blackleg of canola: Coordinating international blackleg research and development	2019-2022	University of Melbourne Ex GRDC	Prof Jacqueline Batley
Dung beetle ecosystem engineers: Taking the science to the paddock	2020	UWA Research Impact Grants	Mr Jacob Berson, Dr Winn Kennington, Prof Leigh Simmons, Prof Raphael Didham and A/Prof Theodore Evans
Disease epidemiology and management tools for Australian grain growers	2018-2020	DPIRD Ex GRDC	Dr Michael Renton

Title	Funding period	Funding body	Investigators
Provision of research services for the Wheatbelt Development Commission 2019	2019	Wheatbelt Development Commission	Prof Fiona McKenzie
Queensland fruit fly trapping grid optimisation	2020	Agribusiness Yarra Valley	Dr Michael Renton
New opportunities for the production of premium and medicinal honey	2020-2021	AgriFutures Australia	Dr Kevin Foster, Prof Megan Ryan, Mr Daniel Kidd, Dr Joanne Wisdom, Ms Tiffane Bates, Dr Kate Hammer and A/Prof Cornelia Locher
Strengthening the weakest link in peri-urban Medfly suppression	2019-2021	Australian Plant Biosecurity Science Foundation	Assoc/Prof Ben White
Identifying genetic contributors to canola blackleg resistance in the presence of environmental effects using Machine Learning	2020-2022	GRDC	Prof David Edwards, Mr Philipp Bayer, Prof Mohammed Bennamoun, Prof Farid Boussaid and Prof Jacqueline Batley
BeefLinks: Systems of beef production from irrigated fodder production in northern Western Australia	2020-2023	MLA	Prof Phil Vercoe, Dr John Milton and Kevin Bell
BeefLinks: “DietID” Feedbase mapping to raise productivity of cattle	2019-2023	MLA	Prof Phil Vercoe, Dr Zoey Durmic and Dr David Walker
Expanding production of priority fruit tree crops for WA	2019-2023	DPIRD	Dr Michael Considine
Program 1 - Project Number 38 - Ngooka honey – Noongar Land Enterprise Group (NLE)	2020-2021	CRC for Honey Bee Products	Dr Bryan Boruff, Assoc/Prof Cornelia Locher, Dr Kate Hammer and Mr John Duncan
Machine Learning - Project E: Deep Learning for early detection and classification of crop disease and stress	2020-2021	GRDC	Prof Mohammed Bennamoun, Prof Farid Boussaid, Prof David Edwards, Dr Philipp Bayer and Dr Nicolas Taylor
Developing strong restorer-of-fertility genes for hybrid wheat breeding	2021-2023	ARC Linkage Projects	Prof Ian Small, Mr Pascual Perez and Dr Tristan Coram
Tightening the phosphorus cycle for grain legumes	2021-2025	ARC Linkage Projects	E/Prof Hans Lambers, Prof Kadambot Siddique, Prof Megan Ryan, A/Prof Peta Clode, A/Prof Rajeev Varshney, Prof Fusuo Zhang, Dr Wenfeng Cong and A/Prof Yifei Liu
Does plasma membrane perception of 2,4-D influence auxin resistance?	2021-2023	ARC Linkage Projects	Prof Stephen Powles and Mr Chad Sayer
Identifying control elements in chloroplast gene expression	2021-2023	ARC Discovery Projects	Prof Ian Small
Ascorbate and glutathione integrate the control of grapevine development	2021-2024	ARC Discovery Projects	Dr Michael Considine, Dr Amanda Walker, Dr Joanne Wisdom and Prof Christine Foyer
Understanding disease resistance gene evolution across the Brassicaceae	2021-2023	ARC Discovery Projects	Prof Jacqueline Batley and Prof David Edwards
Advancing programmable genetic computation to control plant gene activity	2021-2023	ARC Discovery Projects	Prof Ryan Lister
The roles and regulators of new plant cells linked to root transport	2021-2023	ARC Discovery Projects	Prof Ryan Lister and Prof Justin Borevitz

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Industry Advisory Board (IAB)

The IAB provides IOA with industry interaction, advice and feedback. IAB members represent a cross-section of agricultural industries and natural-resource-management areas.

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Farmer

Dr Dawson Bradford
Farmer

Mr Philip Gardiner
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Mr Neil Young
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Business Manager, IOA UWA (until June 2020)

Ms Cora Castens (Executive Officer)
Executive Assistant to the Director, IOA UWA

2020 Publications

In 2020, researchers affiliated with IOA published more than 330 peer-reviewed journal articles, books and book chapters.

Peer Reviewed Journals

Abd-Elmabod SK, Muñoz-Rojas M, Jordán A, Anaya-Romero M, Phillips JD, Laurence J, Zhang Z, Pereira P, Fleskens L, van der Ploeg M and de la Rosa D (2020). Climate change impacts on agricultural suitability and yield reduction in a Mediterranean region. *Geoderma* **374** doi: 10.1016/j.geoderma.2020.114453

Abdi AI, Nichols PGH, Kaur P, Wintle BJ and Erskine W (2020). Morphological diversity within a core collection of subterranean clover (*Trifolium subterraneum* L.): Lessons in pasture adaptation from the wild. *PLoS ONE* **15** (1) doi: 10.1371/journal.pone.0223699

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Al-lami HFD, You MP, Mohammed AE and Barbetti MJ (2020). Virulence variability across the *Alternaria* spp. population determines incidence and severity of alternaria leaf spot on rapeseed. *Plant Pathology* **69:** 506-517 doi: 10.1111/ppa.1313

Al-Lami HRD, You MP and Barbetti MJ (2020). Temperature drives contrasting Alternaria leaf spot epidemic development in canola and mustard rape from *Alternaria japonica* and *A. Brassicae. Plant Disease* **104:** 1668-1674

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Acronyms

ACIAR	Australian Centre for International Agricultural Research
ACMEI	Australian Co-operative and Mutual Enterprise Index
AFI	Australian Farm Institute
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
ANID	Chilean National Agency for Research and Development
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
BLUP	Best linear unbiased prediction
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 Organization
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
HWSC	Harvest Weed Seed Control
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
KBP	Kilo-base pair
LED	Light emitting diode
LiDAR	Light Detection and Ranging
LUANAR	Lilongwe University of Agriculture and Natural Resources
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
RGAs	Resistance Gene Analogs
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
SST	SuperSeed Technologies Pty Ltd
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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