THE UNIVERSITY OF WESTERN AUSTRALIA

Institute of Agriculture

Annual Research Report 2019

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 contribution to the advancement of agriculture and to the management of natural resources in selected international, national and regional settings.

For Western Australia, the Institute 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 the University'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 Western Australia, and allow Western Australia to share its knowledge with the world.

Resourcing: Increasing the pool of resources available for investment in critical RDE&A in Western Australia and in relevant national and international issues.

Front Cover Image: UWA Farm Ridgefield. Image credit: Richard McKenna.

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Director's overview

On behalf of The University of Western Australia, I am pleased to present the 2019 Annual Research Report for The UWA Institute of Agriculture (IOA).

In 2019, collaborative and multi-disciplinary research and development activities have continued across the six research themes: Crops, Roots and Rhizosphere; Sustainable Grazing Systems; Water for Food Production; Food Quality and Human Health; Engineering Innovations for Food Production; and Agribusiness Ecosystems. Through these research themes, IOA has continued its collaborations across UWA's four faculties – the Faculty of Science, Faculty of Health and Medical Sciences, Faculty of Arts, Business and Law, and the Faculty of Engineering and Mathematical Sciences. IOA is also active in building links with UWA's other institutes, including the UWA Oceans Institute and UWA Public Policy Institute.

Communication and engagement activities related to UWA's agricultural research, development and training activities continued throughout 2019. IOA researchers published more than 250 journal articles, book chapters, and reports in 2019, and a total of 24 media statements were distributed throughout the year generating coverage in the regional and international media. We continue to strengthen our engagement with industry, farmer groups, collaborators, funding bodies, and alumni, particularly through our special seminars, annual Postgraduate Showcase and Industry Forum, and involvement in Dowerin Field Days, GRDC Grain Research Updates, and UWA Open Day. More than 400 students, academics and industry leaders visited UWA Farm Ridgefield in 2019, and 4600 participants enrolled in the Massive Open Online Course *Discover Best-Practice Farming for a Sustainable 2050* in 2019.

UWA remained in the top 100 position in global rankings in 2019, including the Academic Ranking of World Universities (99) and Quacquarelli Symonds (91). I was pleased to see that UWA's strong position in Agricultural Sciences in the 2019 Academic Ranking of World Universities, at 1st in Australia and 18th in the world. This significant achievement is made possible through UWA's excellent research, development and teaching activities, dedicated staff and students, and strong support from industry, funding bodies, and committed partners.

Finally, I wish to acknowledge IOA staff, associates, students, Management Board members, Industry Advisory Board and Research Theme Leaders, as well as our national and international collaborators and funding bodies for their continued support and assistance throughout 2019.

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

Chair’s message

The IOA Industry Advisory Board continues to support the Institute towards our common goal of advancing the agricultural and natural resource management sectors in Western Australia and beyond.

In 2019, IOA welcomed Ms Dani Whyte to the Industry Advisory Board. Ms Whyte is an agronomist, Vice President of The Australian Association of Agricultural Consultants (WA), and UWA Agriculture Science graduate. We continue to explore opportunities to renew and expand the skills of the Board to ensure the capacity required to support the IOA.

We are pleased to see that other IOA communication activities have continued to stimulate discussion within the agricultural sector, including the wide range of public lectures and translational activities involving the UWA Future Farm 2050 at Ridgefield.

Each year the Board contributes to the annual IOA Industry Forum, which this year focused on *Finding Common Ground: bringing food, fibre and ethics to the same table*. The forum was well received by the agriculture industry and community, and sparked much discussion on the topic of social license in agriculture.

The Institute continues to maintain strong links to the agricultural sector, and I look forward to supporting this further in the year ahead. I would like to thank IOA members, members of the Board, the IOA Director Hackett Professor Kadambot Siddique and his team, and all those who have supported IOA in its achievements in 2019.

Dr Terry Enright
Chair of the IOA Industry Advisory Board




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Crops, Roots and Rhizospheres

Theme Leaders

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The Crops, Roots and Rhizosphere theme covers all aspects of crop production, both aboveground and belowground. 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 project students and PhD students.

As is evident from the projects included in our section of the annual report, we research a broad range of crops including wheat, lupins, chickpea, field pea, canola and 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. 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.

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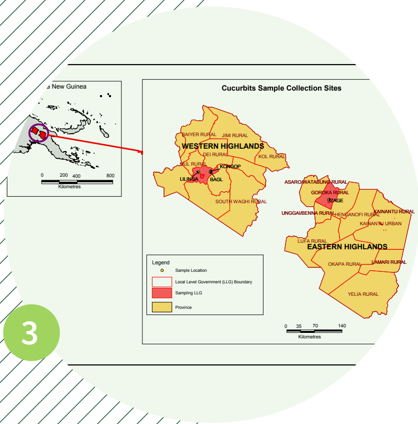

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Crop Genomics and Pangenomics

Project team: Professor Dave Edwards[1] (project leader; dave.edwards@uwa.edu.au), Professor Jacqueline Batley[1], Dr Philipp Bayer[1], Ricky Hu, Clementine Merce, Cassie Fernandez, Robyn Anderson, Monica Danilevicz, Jacob Marsh

Collaborating organisations: UWA; ICRISAT; JIC; BASF; CAAS; EU Horizon2020

The applied bioinformatics group and the Batley laboratory contribute to international projects to sequence the genomes and pangenomes of Brassicas, cereals, diverse legumes and orphan crops.

These assemblies, together with the related annotation and diversity information, permit the association of gene variants with important agronomic traits; information which can accelerate the breeding of these important crops.

In 2019, we published three reference genomes for soybean, the first reference genome for pea, analysis of 429 chickpea varieties, a pangenome for Sesame, and analysis of wheat, barley, lupin, Macadamia and Brassica genomes

Ongoing research includes analysis of extended pangenomes for Brassica species, soybean and banana. These pangenome assemblies capture the gene content of the species rather than one individual and so are more applicable for genomics based crop improvement approaches.

This research is supported by ARC, UWA and BASF

Plant information systems

Project team: Professor Dave Edwards[1] (project leader; dave.edwards@uwa.edu.au), Dr Philipp Bayer[1]

Collaborating organisations: [1]UWA; [2]International wheat information system expert working group; [3]International rice informatics consortium; [4]International Brassica informatics consortium

With the continued exponential growth of data for crop species, from genomes to breeding studies, there is a growing urgency to be able to manage this information for integration and reuse.

Numerous crop specific databases have been developed with diverse functionality relating to their specific user group. There is a growing trend to integrate diverse data at different locations using recently developed IT approaches for database indexing and remote query. Professor Edwards is an international leader in crop database management, contributing to the Brassica information system. He is also co-chair of the wheat information system expert working group, and on the advisory committee for the international rice informatics consortium, supporting both the development of crop specific information systems as well as coordinating standard approaches across species.

Sequencing historic 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[5], Professor Cesar Fribourg[4], Dr Jan Kreuze[4], Dr Segundo Fuentes[4], Professor Kazusato Ohshima[6], Dr Hiroki Matsuoka[6]

Collaborating organisations: [1]UWA; [2]FERA Science LTD, UK; [3]University of Newcastle, UK; [4]National Agrarian University, Peru; [5]Australian National University; [6]Saga University, Japan

This project arises from the need to sequence the genomes of historical virus isolates of agriculturally and environmentally damaging plant virus studied during the era before nucleic acid (RNA and DNA) sequencing became widely used (early 1990's). Sequencing such 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. It also helps avoid virus nomenclature errors such as giving a new name to a virus which already has a name, or using the name of a previously studied virus from the same crop for a virus that is different. Historic sequencing studies also permit evolutionary virologists to date when different virus lineages diverged in the past, giving rise to new lineages or even new viruses. Such dating studies compare old sequences with the new sequences of the same virus to determine its rate of mutation and use this to date when divergences occurred. Some of these may have been triggered by well documented events such as the Irish Potato Famine or the first transportation of a potato from its Andean centre of domestication to Europe.

Using desiccation over silica gel or freeze drying, the historic virus isolates used were preserved in the 1970's and early 1980's. A wide range of viruses from diverse crops in the Andean region of South America and Europe were maintained for 30-40 years in the FERA virus isolate collection in the UK. In 2017-2018, they were subjected to next generation sequencing (NGS) to obtain complete virus genomic sequences. These genomes were compared with others of the same viruses, either newly sequenced or obtained from the GenBank database. Instances of incorrect nomenclature were revealed – both renaming a virus which already had a name and using an existing virus name for a virus that was different. In one instance, an unknown virus isolated in Peru the 1970's was identified and a biological and phylogenetic study undertaken comparing its old and new isolates. Where sufficient genomes were available dating studies were undertaken.

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

1: Map of Peru showing the collection sites of the 10 Wild potato mosaic virus (WPMV) isolates studied. Nine WPMV isolates were collected in the coastal region and a single isolate (CH) in the Andean highlands. Map: Cesar Fribourg, National Agrarian University, Lima, Peru.

2: Symptoms of stunting, mosaic and deformation of leaves in the wild potato *Solanum chancayense* caused by infection with Wild potato mosaic virus isolate TL (healthy plant left). Photograph: Cesar Fribourg, National Agrarian University, Lima, Peru.

Wind spread of plant viral pathogens into northern Australia

Project team: Adjunct Professor Roger Jones[1] (project leader; roger.jones@uwa.edu.au), Dr Solomon Maina[1], Professor Martin Barbetti[1], Dr Owain Edwards[2], Dr David Minemba[1,4], Mr Michael Areke[5]

Collaborating organisations: [1]UWA (SAgE and IOA); [2]CSIRO Land and Water; [3]DPIRD; [4]National Agricultural Research Institute, Lae, Papua New Guinea; [5]National Agriculture Quarantine and Inspection Authority, Port Moresby, Papua New Guinea

Australian crops face threats from damaging new viruses or virus strains arriving via infectious insect vectors blown across the sea in wind currents from Indonesia, East Timor and PNG. This study sought to establish the extent to which economically important viral pathogens are arriving in northern Australia in this way. The approach was to search for 'genetic connectivity', a term used when genetically similar viral sequences occur amongst virus populations from different countries. Such connectivity indicates virus spread between them, in this case by crossing the sea separating Australia from its northern neighbours.

In the project's final phase, we obtained new complete genomic nucleotide sequences of *Zucchini yellow mosaic virus* (ZYMV) and *Papaya mosaic virus* (PRSV) isolates from cucurbit crops in PNG. We compared these with our earlier genomic sequences of both viruses from cucurbits East Timor or across northern Australia, and with others from elsewhere retrieved from GenBank.

In 2019, we published two papers. The first reported evidence of genetic connectivity between genomes of PRSV from cucurbits from PNG and across northern Australia. The second found no evidence of this with ZYMV isolates from similar locations, but reconfirmed the genetic connectivity reported earlier between ZYMV isolates from northern Western Australia and East Timor. A plausible explanation is that strains of both strains have spread recently across the sea into northern Australia

This research is supported by Cooperative Research Centre for Plant Biosecurity CRCPB Canberra, CSIRO, DPIRD and UWA.

3: Map of Papua New Guinea (PNG) showing the four locations in the Western and Eastern Highlands where leaf samples infected with *Papaya ringspot virus* (PRSV) were collected from cucurbit crops. The province in which Bagl, Kongop and Lilinga are located is Mount Hagen, and where Zage is located is Goroka. Graphics support with map kindly provided by Dr Kila Waiyo.

4: Cucumber plant with mosaic symptoms growing in the field in Zage, Goroka, Eastern Highlands Province, PNG. Image provided by Dr David Minemba.

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], Professor Kadambot Siddique[1], Mr John Quealy[1], Dr Rajneet Uppal[2], Mr Andrew Carmichael[2], Mr John Bromfield[2], Mr Mathew Dunn[2], Mr 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 new 5-year GRDC national project, led by UWA, is built upon previous GRDC investment in the National Brassica Germplasm Improvement Program and international collaboration among Australia, China and India in canola. This new project aims 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 canola heat stress tolerance.

In 2019, experiments were conducted in controlled-environment rooms at UWA to assess the response of 24 canola genotypes to heat stress. Some heat-tolerant and heat-susceptible germplasm were identified for validation in future field experiments. In 2019, field-based experiments were conducted in portable heat chambers by NSW DPI Wagga Wagga, and UWA sub-contracted DPIRD (WA) to conduct a shade-house heat experiment at Geraldton, WA.

Seed increase of 50 new genotypes with putative heat tolerance occurred in Chile in 2019-20, for field testing in 2020 by project partners. Protocols for heat stress field trials were established in consultation with project partners and biometrics experts in GRDC Statistics for Australian Grains Industry project (SAGI-West). Heat stress field trials in 2020 will be sub-contracted to regional research stations of DPIRD (WA) and NSW DPI.

At UWA Shenton Park Field Station in 2019, two novel heat-stress plastic tunnel houses were built as proto-types for heat tolerance screening in canola breeding programs. The heat-stress tunnel houses are connected to 2 screenhouses, where canola plants are grown before and after heat stress treatment under optimal growth conditions. Plants will be well-watered at all times to avoid confounding of results due to drought stress. Individual plants will be moved into the heat-stress tunnel house at first flower for one week, which is the most heat-sensitive growth stage. Previous results show that yield on the main stem is greatly reduced by heat stress at the early flowering stage, and current canola genotypes never fully recover from this heat stress. We expect to find heat tolerant genotypes with lower yield loss on the main stem and higher rates of recovery from heat stress at flowering. These heat stress chambers will be useful as prototypes for heat tolerance screening in commercial canola breeding programs.

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 GRDC, UWA, and NSW DPI.

5: Newly constructed controlled environment rooms connected to existing screen-houses for canola heat-tolerance screening at the flowering stage.

6: Screen-house with automatic reticulation system for canola plant growth before and after heat stress treatment under optimal growth conditions.

Identifying and characterising Resistance to *Leptospaheria maculans* (Rlm) candidate genes in *Brassica* species

Project team: Professor Jacqueline Batley[1] (project leader; jacqueline.batley@uwa.edu.au), Professor Dave Edwards[1], Dr Philipp Bayer[1], Ms Anita Severn-Ellis[1], Ms Soodeh Tirnaz[1], Ms Yueqi Zhang[1], Ms Nur Shuhadah Mohd Saad[1], Mr Aldrin Cantila[1], Ms Tingting Wu[1], Mr Junrey Amas[1], Ms Linh Ton[1]

Collaborating organisations: [1]UWA

Blackleg disease accounts for more than 58% of the total yield losses suffered by the Australian canola industry each year. The disease is caused by the fungal pathogen *Leptosphaeria maculans*, which colonises the host's stem cortex, resulting in cankers forming at the base of the stem, and subsequent lodging.

Resistance (*R*) genes in canola recognise and overcome fungal infection by the *L. maculans* carrying corresponding *Avr* genes, in a direct gene-for-gene interaction. While most of the *Avr* genes in *L. maculans* have been cloned, only three of the sixteen major *R* genes have been identified and cloned.

Both cloned *LepR3* and *Rlm2* genes are allelic variants on chromosome A10, but interact with different *Avr* genes. *AvrLm1-L3* and *AvrLm2* are tightly linked genes on *L. maculans* scaffold 6, which is recognised by the allelic variants *LepR3* and *Rlm2*, respectively. *AvrLm1-L3* also interacts with *Rlm1*. QTL analysis mapped *Rlm1* on *B. napus* chromosome A7.

Phenotyping test demonstrated *AvrLm1-L3* recognition of both *LepR3* and *Rlm1* gene products, manifesting in hypersensitive resistant response. However, phenotyping test could not distinguish between the two genes. The project aims to sequence and screen Australian cultivars for cloned (*Rlm2* and *LepR3*) and candidate *R* genes (*Rlm1* and *Rlm4*).

The highlights from this research include:

- Validating phenotype scores with PCR genotype results
- Generate whole-genome sequence for Australian canola cultivars for future downstream analysis

This research is supported by UWA International Student Research Training Program.

7: Growing and bulking canola for screening in glasshouse facilities (a), and utilising PCR to screen for presence and absence of genes of interest (b-c).

Pre-breeding of canola and peas

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

Collaborating organisations: [1]UWA

In 2019, UWA and NPZ in Germany celebrated 20 years of collaboration on pre-breeding of canola and peas at UWA. Research continued into a rapid breeding method using best linear unbiased prediction (BLUP) of breeding values and optimised mating designs. Estimated breeding values (EBVs) for yield and other traits are combined into an economic index of genetic value, expressed in $/ha. BLUP or genomic BLUP values were calculated for grain yield, disease resistance and seed quality. EBVs were integrated into an economic index and optimised mating designs are generated by optimal contribution selection (OCS). Data were integrated across cycles of selection (the "animal model") to improve predictions. The methods provided superior long-term genetic gain with reduced rates of population inbreeding. Results from three cycles of rapid canola breeding (2014-2018) were presented by the Chief Investigator Professor Wallace Cowling at the International Rapeseed Congress in Berlin in 2019.

MSc students Felipe Castro and Maria del Pilar Urricariet evaluated field peas for genetic improvement based on rapid recurrent selection with OCS. In 2019, the progeny were evaluated in the field for black spot resistance, grain yield, and stem strength. The genetic association of EBVs between pairs of traits were evaluated using bivariate pedigree analysis.

The results from the canola pre-breeding project are being translated into commercial canola hybrids by the project funder, NPZ Lembke, Germany. NPZ has licensed or sold canola hybrids from the UWA pre-breeding programme to several partners in Australia and internationally.

The canola breeding project contributed to UWA's high ranking in Engagement and Impact, assessed by the Australian Research Council in 2018 (project UWA07).

This research is supported by NPZ Australia Pty Ltd, NPZ Lembke, Germany, and UWA.

8: Rapid breeding of canola starts with crossing in an optimised mating design by Jasenka Vuksic and Rozlyn Ezzy in the canola pre-breeding group at UWA.

9: MSc students Felipe Castro and Maria del Pilar Urricariet in field pea trial in 2019 at UWA Shenton Park.

Ensuring Lucerne seed production in the absence of bees

Project team: Adjunct Professor John Hamblin[1] (project leader; john.hamblin@uwa.edu.au), Professor Martin Barbetti[1], Mrs Freda Blakeway[2]

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

In 2015, a project seeking self-pollinating ability in a range species reported to have increased yields in the presence of bees included two crops widely recognised as having an essential requirement for bee pollination (Lucerne and Melons) to set seed or fruit.

That work identified genotypes in all but one species that showed no response to the presence of bees. The exception was Lucerne, where only a single variety was used (SARDI 10). In the absence of bees, no seed was set. In melons, self-pollinating types were identified, but 750 different genotypes were screened, rather than one.

In 2017, seeds from a SARDI population involving 40 open pollination parental lines were planted in a bee exclusion cage. Approximately 800 survived but none set seed. The plants were cut back and when re-flowering, bees were placed in the cage for 4 weeks and seeds were gathered.

In 2018, approximately 100,000 plants were grown at very high density in a bee proof enclosure. Some 25 were found with pods. The latter plants were transplanted into pots and then, when over initial transplant shock, were grown in a small bee proof enclosure to set seed. Several set significant quantities of seed in the absence of bees.

In 2019, the 6 best lines were tested with and without bees. Segregation is continuing within these plants for a range of characters including flowering time, growth habit and seed set. Future directions for this project are currently under discussion with AgriFutures Australia.

This research is supported by AgriFutures Australia (project PRJ-01875) and SST.

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), Hackett Professor Kadambot Siddique[1], Dr Renu Saradadevi[1], Dr Clare Mukankusi[2], Ms Winnifred Amongi[2], Mr Jean-Claude Rubyogo[2], Dr Teshale Assefa[2], Ms Annuarite Uwera[5], Dr Berhanu Fenta[6], Mr Eric Nduwarugira[8], Mr Julius Mbiu[7], Dr Reuben Otsyula[3], Dr Stanley Nkalubo[4]

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

Common bean (*Phaseolus vulgaris*) is a major dietary component of the rural and urban populations of the East and Central African region. Beans provide iron (Fe) and zinc (Zn) which are particularly important to the health and well-being of African women and children, and also protein to help sustain the entire household of women, men and children. This ACIAR-funded project brings together experts in new crop breeding methods in Australia with six partner countries in east Africa to undertake rapid breeding and variety development for reduced cooking time and higher Fe and Zn content. This project will also distribute new varieties through the Pan Africa Bean Research Alliance (PABRA).

Bean production and consumption in Africa is hindered by the very long time needed for soaking and cooking. Several studies indicate that cooking time is heritable and should be reduced quickly with employment of rapid breeding methods.

This project aims to employ new breeding methods based on pedigree and genomic selection together with optimal contribution selection (OCS) to accelerate breeding of common bean for rapid cooking time and higher Fe and Zn content. The project is based at the bean breeding program of the International Centre for Tropical Agriculture (CIAT) in Uganda and includes partner countries Ethiopia, Kenya, Uganda, Tanzania, Rwanda and Burundi. Our goal is to reduce cooking time in African common bean by at least 30%, and increase Fe content by 15% and Zn by 10% during the 5 years of this project.

In 2019, we surveyed the grain yield, cooking time, Fe and Zn content in more than 350 African bean varieties from six major market class groups. 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 late 2019.

We will carry out annual cycles of crossing and selection based on 1000 progeny per cycle for grain yield, cooking time, Fe and Zn. Project partners will test seed of lines from the breeding programme each year and will select locally adapted genotypes within known market classes.

All field and laboratory data from partner countries will be incorporated into a common database system (BMS) that will link genotypes and phenotypes across the partners. Pedigree information will be combined with genomic information in each crossing cycle to improve accuracy of GEBVs and to improve the optimised mating design through OCS.

Partners will release new bean varieties in relevant markets in east Africa through the CIAT/PABRA networks during and after the project.

This research is supported by ACIAR.

10: Team members of the ACIAR bean breeding project.

11: A bean seller in Kampala, Uganda, with her high quality beans for sale. She indicated there is a higher price for beans which cook faster.

Unravelling the genetic control of flowering time in narrow-leafed lupin

Project team: Professor Wallace Cowling[1] (project leader; wallace.cowling@uwa.edu.au), Dr Candy Taylor[1], Dr Renu Saradadevi[1], Dr Matthew Nelson[2], Dr Jens Berger[2], Dr Lars Kamphuis[2,4], Dr Darshan Sharma[3], Dr Gagan Garg[2], Professor Karam Singh[2,4], Dr Federico Ribalta[1], Dr Janine Croser[1]

Collaborating organisations: [1]UWA; [2]CSIRO Floreat; [3]DPIRD; [4]Curtin University

A single gene (*Ku*) has been used to breed narrow-leafed lupins with early flowering times and which are adapted to warm, short-season environments, such as those in the northern Western Australian (WA) wheatbelt. However, in order to expand the lupin industry in Australia, particularly in the southern WA wheatbelt and eastern states, and to diversify the genetic background of domesticated lupins, it is necessary to increase the range of flowering times present in modern varieties available to farmers and the number of flowering time genes at the disposal of breeders.

Our group recently discovered two new variations of the *Ku* gene by studying the genomic location of *Ku* in European lupin varieties and wild lupins from the Mediterranean region. Some European varieties carry a variant known as *Julius*, which is genetically distinct but functionally equivalent to *Ku* in terms of flowering time. A second variant (from a wild lupin) enables a novel mid-season flowering time that is potentially valuable for mid-high rainfall environments. All of these flowering time variants bring with them a new genetic background of potential value to Australian lupin breeding.

In 2019, we conducted a field trial to evaluate field performance of these two new flowering time genes, and tested their association with plant biomass and grain yield. The lupins tested in these trials were the third-generation progeny (F_3) from crosses between the new genes and traditional Australian lupin varieties. We tagged individual plants and recorded the status of their domestication traits (flower colour, foliage colour, alkaloids, seed hardiness, etc) in addition to flowering time and grain yield. Low alkaloid and soft-seeded progeny with the new flowering genes were identified in this trial and will be sown in a second field trial in 2020 to validate the results.

In addition to this work in the field, work in the laboratory aimed to develop new genetic markers to identify each variation of the *Ku* gene. This will provide a new tool which breeders may use to quickly establish the genetic background and flowering time of new breeding lines in the future.

Finally, our group and collaborators have also been seeking to determine the genomic location of a second, lesser-used flowering time gene (*efl*), with the aim of increasing the efficiency at which this gene can be adopted by breeders again as a source of mid-late season flowering times. We used a sixth-generation (F_6) genetic population, comprising of 185 individuals, to trace the genomic location of *efl* and to identify candidate genes and mutations which may underlie *efl*. We will validate our results from this study in 2020.

COGGO Research Project #3 2019 supported a Research Officer position for Dr Renu Saradadevi, and GRDC research project DAW00238 supported the PhD scholarship of Dr Candy Taylor, who graduated PhD in December 2019.

This research was supported by GRDC (DAW00238), COGGO Research Fund 2019 Project #3, and UWA.

12: Segregation of flower colour in narrow-leafed lupin F_3 population.

13: Segregation of flowering time in narrow-leafed lupin F_3 population.

Adaptation of castor bean plants to adverse soil stresses

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

Collaborating organisations: [1]UWA

Castor bean (*Ricinus communis* L) is a perennial flowering plant species in the spurge family, Euphorbiaceae. Castor seed is one of the important non-edible oilseeds, having immense industrial and medicinal value. Castor seed is the source of castor oil which has a wide variety of uses. The seeds contain between 40 and 60% oil that is rich in triglycerides, mainly ricinolein. Castor oil and its products are widely utilised in manufacture of nylon fibres, jet-engine lubricants, hydraulic fluids and other products. In Australia, castor plants are seen occasionally growing in parks, riversides, and wasteland. However, commercial production of castor crop is not available in Australia, despite its wide distribution in tropical and subtropical regions, particularly in India and China. Funded by Virtue Australia Foundation, this project aims to evaluate the growth and production of castor bean genotypes under controlled and field environments and the adaptation of imported genotypes to Western Australian soil, where abiotic stresses such as drought and salinity are in place.

In 2019, several experiments were conducted to (1) determine the suitability of ground water collected from Marvel Loch farm for irrigating castor bean plants using farm soil and potting mix, (2) investigate fertilisation including nitrogen and mineral rocks, microbial application and effects of cadmium (Cd) stress on root development and plant growth, and (3) grow the imported Chinese variety in the field environments. The results showed that ground water significantly delayed seed germination and early growth, killing plants grown using field soil. Cadmium stress suppressed both shoot and root growth, and high concentrations of nitrogen also inhibited plant growth. Results showed that application of mineral rocks and microbes both enhanced seed germination seedling growth, while chemical fertiliser significantly delayed seed germination, even constrained seed germination with or without Cd. Plants showed some toxic symptoms under Cd stress.

Follow-up experiments are in progress to further evaluate castor bean adaptation to soil salinity and to develop techniques for producing castor hybrids with high yield, high oil content and improved adaptation to WA dryland environment.

This research is supported by Virtue Australia Foundation.

14: Imported high-yielding castor bean genotype "Zibo" are well established in the field soil at UWA's Shenton Park Field Station.

Micronutrients including iron, zinc and copper in mature leaves provide precise indication of belowground carboxylate-releasing processes in chickpea

Project team: Mr Zhihui Wen[1,2], Dr Jiayin Pang[1], Professor Hans Lambers[1], Professor Megan Ryan[1], Professor Jianbo Shen[2], Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au)

Collaborating organisations: [1]UWA (SBS, SAgE and IOA); [2]China Agricultural University

The release of carboxylates is a well-known phosphorus (P)-mobilising strategy to enhance plant P acquisition for plants grown under low P conditions. Carboxylates mobilise not only soil inorganic and organic P in the rhizosphere, but also a range of micronutrients, such as manganese (Mn), iron (Fe), zinc (Zn) and copper (Cu). Our previous study demonstrated that leaf [Mn] was positively correlated with the amount of carboxylates in rhizosheath using 100 chickpea genotypes with diverse genetic background, when grown under low P. However, whether the leaf concentrations of other micronutrients such as [Fe], [Zn] and [Cu] could also be used as proxy for rhizosheath carboxylate processes remains largely unknown.

To understand the relationship between leaf micronutrients, including leaf [Fe], [Zn] and [Cu], and rhizosheath carboxylates, data from two glasshouse studies with different growth media, P sources and levels were investigated. In the first experiment, we grew 100 chickpea genotypes with diverse genetic background in a low-P sterilized river sand (10 mg P kg^{-1} soil as insoluble $FePO_4$). In the second experiment, we selected 20 chickpea genotypes (10 with relatively high- and another 10 with relatively low amounts of rhizosheath carboxylates based on results from the first experiment), grown under three P treatments (severely limiting P: 10 mg P kg^{-1} soil as insoluble $FePO_4$; moderately limiting P: 10 mg P kg^{-1} soil as soluble KH_2PO_4; adequate P: 50 mg P kg^{-1} as soluble KH_2PO_4) in a soil mixed substrate.

We found that mature leaf micronutrient concentrations ([Mn], [Fe], [Zn] and [Cu]) can be used to indicate belowground carboxylate-releasing processes in a large set of chickpea genotypes grown under contrasting soil P availability, but leaf [Zn] and [Cu] did not lead to a signal as stable as that provided by leaf [Mn] and [Fe]. More specifically, the results of the sand culture showed that [Mn], [Fe] and [Zn] of mature leaves were positively correlated with the amount of rhizosheath carboxylates under low-P supply. The results from the second experiment using the mixture of field soil and river sand further extended the findings from the river sand under low P supply, by showing that leaf [Mn] and [Fe] had significant positive correlations with rhizosheath carboxylates under both low- and high soil P availability. However, leaf [Zn] and [Cu] only showed the significant correlations with rhizosheath carboxylates under low-P conditions.

Our findings emphasise that in addition to leaf [Mn] as previously found (Pang et al. 2018), [Fe], [Zn] and [Cu] in mature leaves of chickpea can be used as an easily measurable proxy for the assessment of belowground carboxylate-releasing processes in a range of chickpea genotypes. This relationship observed in chickpea may also be applicable to other crops, especially grain legumes, therefore providing valuable screening tools in breeding crops for a high P-acquisition efficiency that use a P-mobilising strategy.

This research is supported by IOA, China Agricultural University, and Chinese Scholarship Council.

15: A large set of chickpea genotypes grown in the glasshouse.

A significant increase in rhizosheath carboxylates and greater specific root length in response to terminal drought are key for higher relative phosphorus accumulation in chickpea genotypes

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

Collaborating organisations: [1]UWA

Chickpea (*Cicer arietinum* L.) is the world's third most important grain legume crop, occupying 14.5 Mha of agricultural land, but its sustainable production is challenged by drought stress. Drought stress decreases the rate of photosynthesis, stomatal conductance and CO_2 fixation and assimilates translocation, resulting in less assimilate production for growth and yield of plants. Phosphorus (P) acquisition is also reduced significantly in dry soil due to its slow movement in the soil via diffusion.

This study aimed to investigate the effects of terminal drought on phosphorus (P) acquisition, together with root morphological and physiological traits associated with P-acquisition in chickpea.

Four chickpea genotypes were grown in cylindrical pots filled with 3 kg of soil with a low P level in a glasshouse. Two water treatments, well-watered and water-stress were imposed. At the reproductive stage, water was withheld completely for the water-stressed treatment (terminal drought) while water was maintained at 70% field/pot capacity for the well-watered treatment. Plants were harvested when water-stressed plants fully closed their stomata.

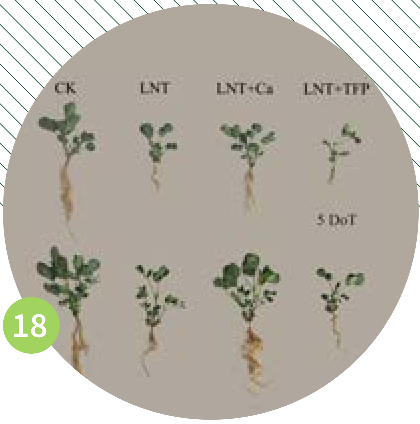
In response to drought stress, all four genotypes reduced shoot and root growth, root mass ratio, and shoot P content. However, specific root length, water-use efficiency and the amount of carboxylates in the rhizosheath increased significantly. Among all genotypes, ICC2884 had the highest relative shoot growth rate, relative shoot P-accumulation rate, and physiological P-use efficiency when grown under low-P and drought stress.

Our results suggest that ICC2884 can be used as a parental genotype in chickpea breeding programs targeted to develop new cultivars for low-P and terminal drought environments.

This research is supported by UWA.

16: Licor measurements.

17: Randomised block design of experiment.



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Supplementary calcium restores peanut (*Arachis hypogaea*) growth and photosynthetic capacity under low nocturnal temperature

Project team: Professor Hans Lambers[1] (project leader; hans.lambers@uwa.edu.au), Associate Professor Yifei Liu[1,2], Dr Jiayin Pang[1], Professor John Yong[1,3], Dr Yinglong Chen[1], Associate Professor Chunming Bai[4], Clément Gille[1], Qiaobo Song[2], Qingwen Shi[2], Xiaori Han[2], Tianlai Li[2], Professor Kadambot Siddique[1], Professor Hans Lambers[1,5]

Collaborating organisations: [1]UWA (SBS, SAgE and IOA); [2]Shenyang Agricultural University, Shenyang, China; [3]Swedish University of Agricultural Sciences, Sweden; [4]Liaoning Academy of Agricultural Sciences, China; [5]China Agricultural University, Beijing, China

Peanut (*Arachis hypogaea* L.) is a globally important oil crop, which often experiences poor growth and seedling necrosis under low nocturnal temperatures (LNT). This study assessed the effects of supplementary calcium (Ca^{2+}) and a calmodulin inhibitor on peanut growth and photosynthetic characteristics of plants exposed to LNT, followed by recovery at a higher temperature. We monitored key growth and photosynthetic parameters in a climate-controlled chamber in pots containing soil. LNT reduced peanut growth and dry matter accumulation, enhanced leaf non-structural carbohydrates concentrations and non-photochemical quenching, decreased the electron transport rate, increased the transmembrane proton gradient, and decreased gas exchange rates. In peanuts subjected to LNT, foliar application of Ca^{2+} restored growth, dry matter production and leaf photosynthetic capacity. In particular, the foliar Ca^{2+} application restored temperature-dependent photosynthesis feedback inhibition due to improved growth/sink demand. Foliar sprays of a calmodulin inhibitor further deteriorated the effects of LNT which validated the protective role of Ca^{2+} in facilitating LNT tolerance of peanuts.

This research is supported by Natural Science Foundation of China (31772391), Natural Science Foundation of China (31301842, 31601627), National Key Research and Development Plan (2018YFD0201206), Sheng Jing Talents Project (RC170338), China Scholarship Council Project (CSC 201708210143), and National Peanut Research System (CARS-13- Nutrient Management).

18: Effect of exogenous calcium (Ca2+) and a calmodulin inhibitor (TFP) on peanut growth after five days of low nocturnal temperature (LNT) (5 DoT) followed by five days of recovery (5 DoR). CK, normal nocturnal temperature of 20°C/normal daytime temperature of 25°C + foliar spray of type 1 ultrapure water; LNT, low nocturnal temperature of 10°C/normal daytime temperature of 25°C + foliar spray of type 1 ultrapure water; LNT+Ca, low nocturnal temperature of 10°C/normal daytime temperature of 25°C + foliar spray of 15 mmol·L–1 CaCl2; LNT+TFP, low nocturnal temperature of 10°C/normal daytime temperature of 25°C + foliar spray of 5 mmol·L–1 TFP.

Phosphorus-fertilisation has differential effects on leaf growth and photosynthetic capacity of peanut (*Arachis hypogaea* L.)

Project team: Professor Hans Lambers[1] (project leader; hans.lambers@uwa.edu.au), Associate Professor Yifei Liu[1,2], Qingwen Shi[2], Dr Jiayin Pang[1], Professor Jean Yong[1,3], Associate Professor Chunming Bai[4], Dr Caio Guilherme Pereira[1,5], Qiaobo Song[2], Di Wu[2], Qiping Dong[2], Feng Wang[1]

Collaborating organisations: [1]UWA (SBS, SAgE and IOA); [2]Shenyang Agricultural University, China; [3]Swedish University of Agricultural Sciences, Sweden; [4]Liaoning Academy of Agricultural Sciences, China; [5]Massachusetts Institute of Technology, USA

The objectives of this study were to assess how *Arachis hypogaea* L. (peanut or groundnut) responds to different P supplies in terms of growth and photosynthesis, and to determine the optimum P supply and differential P stress thresholds.

We investigated biomass production, leaf expansion, photosynthetic parameters, relative chlorophyll concentration, P700 parameters and chlorophyll fluorescence in a climate-controlled chamber at different P supplies (0.1, 0.5, 1, 1.5, 2 mM).

Both deficient and excessive exogenous P supplies significantly reduced leaf growth, relative chlorophyll concentration and dry matter production in two high-yielding peanut cultivars. The optimum P range was 0.8-1.1 mM for peanut seedlings. Through principal component analysis (PCA) and data fitting, we found that the trade-off of the normalised actual quantum yield [Y(II)] and non-regulatory quantum yield [Y(NO)] in photosystem II (PSII) under light is one of the best proxies to determine the suboptimal, supraoptimal, deficient and toxic P supplies. This is because they are the two key factors with major positive and negative effects of PC1, accounting for 75.5% of the variability. The suboptimal P range was 0.41-0.8 mM and the supraoptimal P range was 1.1-1.72 mM. The suboptimal P supplies corresponded with a leaf P concentration range of 4.8-8.1 mg P g^{-1} DW, while the supraoptimal P supplies corresponded with a leaf P concentration range of 9.9-12.2 mg P g^{-1} DW.

Both deficient and toxic P levels severely inhibited leaf growth and photosynthesis of peanut, and these unfavourable conditions were associated with significant reduction of biomass and photosynthesis, and photodamage extending beyond PSII. The trade-off of the normalised Y(II) and Y(NO) is a useful benchmark to demarcate deficient, suboptimal, supraoptimal and toxic P-fertilisations levels in *A. hypogaea*.

This research is supported by Natural Science Foundation of China (31772391), Natural Science Foundation of China (31301842), National Key Research and Development Plan (2018YFD0201206), Sheng Jing Talents Project (RC170338), China Scholarship Council Project (CSC 201708210143), and National Peanut Research System (CARS-13- Nutrient Management).

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

Project team: Mr Mohammad Moinul Islam[1,6,] Dr Zakaria M. Solaiman[1] (project leader; zakaria.solaiman@uwa.edu.au), Professor Zed Rengel[1], Professor Lynette Abbott[1], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA (SAgE and IOA); [2]DPIRD; [3]FFLI Group Pty Ltd; [4]Premium Hemp Australia; [5]WA Hemp Growers' Co-op Ltd (HempGro); [6]Breeding Division, Bangladesh Jute Research Institute

Industrial hemp (*Cannabis sativa* L.) is one of the most ancient domesticated crops, cultivated for millennia. It is potentially an important crop in Australia for fibre (extracted from stem) or oil and protein (from seeds) since been legalised in 12 November 2017. Industrial 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, meaning it grows well in arid regions. Industrial hemp has a high concentration of nutrients in its roots and leaves that are left in the field after harvest, and thus, soil nutrients are conserved.

This project aimed to provide the scientific basis for the industry to introduce industrial hemp into the monoculture-based crop-growing areas of south Western Australia. This 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, as well as the use of mineral-based fertilisers and biofertiliser will provide environmental sustainability in south Western Australia. The published research outcomes will enable the crop and fibre industry to refine their fertiliser and other agronomic 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 2019, seed germination and early growth of seedlings of 14 industrial hemp varieties were assessed in Petri dish and glasshouse conditions. Significant variations were observed among the varieties with respect to seed germination and seedling growth. Regarding seed germination, variety Han FNQ performed best in both Petri dish and glasshouse, whereas variety Han NE had the highest seedling length and growth rate. The variety Puma 3 showed the highest biomass as it had higher shoot weight and leaf area. These three varieties also had the highest seedling vigour, indicating their potential as new cultivars in Western Australia for fibre, seed and biomass production.

Dietary nutrient concentration in seeds of 14 industrial hemp varieties was also assessed regarding six macronutrients (Ca, K, Mg, Na, P and S) and 12 micronutrients or trace metals (Al, As, Cd, Co, Cu, Fe, Mn, Mo, Pb, Zn, Cr and Ni). Significant variations were observed among the varieties with respect to different macro- and micronutrients concentration. Seeds of the French variety Felina 32 are rich in dietary mineral concentrations among the 14 industrial hemp varieties used in this study. They had the highest concentration of four macronutrients (Ca, P, Mg, Na) and five micronutrients (Al, Cu, Fe, Mo and Zn) out of the 18 macro- and micronutrients considered in the study, indicating the nutritional potential of this variety for seed production for human consumption.

This research is supported by the Australian Government International Research Training Program (RTP) PhD Scholarship and SAgE research grant.

19: Setting up germination trial of 14 industrial hemp (*Cannabis sativa* L.) varieties in glasshouse.

20: Germinated seedlings of industrial hemp (Cannabis sativa L.) varieties in glasshouse.

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Response of maize genotypes with contrasting root system architecture to salt stress

Project team: Dr Yinglong Chen[1] (project leader; yinglong.chen@uwa.edu.au), Mr Hao Wang[2,3], Miss Tingting An[2,3], Professor Bingcheng Xu[2,3], Professor Suiqi Zhang[2,3], Professor Xiping Deng[2,3], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, China; [3]Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, China

Soil salinity is a major abiotic stress, affecting 250 million hectares of irrigated land globally. The area affected by salinity will increase with excessive irrigation and climate change, due to salt intrusion/deposition caused by increasing sea-levels or rainwater, leading to the continued loss of arable land and decreased crop productivity. Maize is susceptible to salinity but shows genotypic variation for salt tolerance. In 2019, two glasshouse experiments were conducted to investigate (1) variations in 20 maize genotypes with contrasting root architecture traits (selected from a root phenotyping study) in response to salt stress, and (2) the mechanisms of arbuscular mycorrhizal fungi (AMF) on alleviation salt stress in host plants through the mitigation of ionic imbalance.

Large variation in 12 measured shoot and root traits was observed among the 20 genotypes under NaCl treatments (50 or 100 mM NaCl for 10 days) using our established semi-hydroponic phenotyping platform. Salt stress significantly decreased biomass production by up to 54.1% in shoots and 37.2% in roots compared with the non-saline control. The salt-tolerant genotypes (such as Jindan52) had less reductions in growth, lower shoot Na^+ contents and higher shoot K^+/Na^+ ratios under salt stress. Primary root depth is a critical trait for identifying salt responsiveness in maize plants and could be used as a selection criterion for screening salt tolerance of maize during early growth. The selected salt-tolerant genotypes have potentials for cultivation in saline soils and for developing high-yielding salt-tolerant maize hybrids in breeding programs.

Inoculation with AMF *Funneliformis mosseae* had a more pronounced effect on shoot growth of the salt-tolerant genotype JD52, compared with a more pronounced effect on root growth of the salt-sensitive genotype FSY1, due to relatively higher root colonization by the fungus in the former genotype. Under salt stress, AM inoculation downregulated iron transporter genes *ZmSOS1* and *ZmNHX* in roots and *ZmNHX* in shoots of JD52, downregulated ZmSOS1 in shoots and roots and upregulated ZmHKT1 in shoots and *ZmNHX* in roots of FSY1. The higher rate of Na^+ translocation from shoots to roots relative to K^+ and the higher K^+: Na^+ ratio in shoots in AM-inoculated plants, particularly FSY1, maintained the structural integrity of chloroplasts in mesophyll cells and thus improved growth performance by AMF in maize exposed to salinity. This study suggests that AM symbiosis improved salt tolerance in two maize genotypes with contrasting root systems through differential regulation of expression of ion transporter genes involved in Na^+/K^+ homeostasis and resultant partitioning/accumulation in plant organs.

This research is supported by National Natural Science Foundation of China, Chinese Academy of Sciences' "Hundred Talent" Program.

21: Maize plants inoculated with AM fungus (right two plants) under 100 NaCl stress (middle two plants).

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]

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

Fine root endophytes (FRE) are symbiotic fungi that provide nutrients they've accessed from the soil to a host plant, in return for energy (carbon) from the plant. Historically, FRE have been incorrectly classified as arbuscular mycorrhizal fungi (AMF) and little is known about FRE.

Through this project we aim to investigate the abundance, diversity, and function of FRE in Australian agricultural and natural ecosystems in response to recent genetic data proving they are taxonomically distinct from the well-studied AMF. Fine root endophytes are found around the globe.

In Australia, we know that FRE are abundant in cereal cropping and pasture systems in southern Australia, but little is known about other agricultural systems, or if the communities of FRE change along environmental gradients.

The project has used an interdisciplinary team of students and early-, mid-and late-career scientists from three countries to complete a comprehensive field survey, novel molecular analyses and innovative glasshouse experiments. Outcomes will include globally significant insights into fine root endophytes and their role in plant growth. The project will strengthen capacity to predict impacts of global environmental change on ecosystem functions driven by the soil rhizosphere.

In 2019, we sampled agricultural systems and their nearby natural ecosystems across four states in Australia (Queensland, Western Australia, Northern Territory, and Tasmania). Across these states, we collected soils for chemical analyses, vegetation data, root samples from which we extracted and sequenced DNA to identify FRE among other fungi, and obtained climatic data. We have collected data from a large array of agricultural systems (e.g. truffle farm, pastures, apple orchard, cereal cropping) across 12 biomes (e.g. desert shrublands, tropical rainforests, montane grasslands).

Data analysis is not yet complete, but preliminary results suggest that FRE are much more diverse than previously thought. We found 177 operational taxonomic units belonging to FRE taxa. We also found that FRE are more abundant and diverse in wetter environments, such as tropical and temperate rainforests. Finally, these preliminary results also show that communities of FRE differed between farming systems and their nearby natural ecosystems.

This research is supported by Australian Research Council Discovery grant (DP180103157).

22: Example of the paired-design between agricultural and natural sites. Here we show the example of a pasture (A) located at a high elevation in Tasmania, and its surrounding native environment (B).

The root and shoot characteristics that enable sweet potato to grow in low phosphorus soils

Project team: Dr David Minemba, Professor Megan Ryan (project leader; megan.ryan@uwa.edu.au), Associate Professor Deirdre Gleeson, Associate Professor Erik Veneklaas, Adjunct Professor Ann Hamblin

Collaborating organisations: [1]UWA

Sweet potato has adapted to marginal soils across a wide range of growing environments after its introduction to many countries outside its centre of origin in South America thousands of years ago. Today, with well over 5000 cultivars used globally, it has become an important staple food crop, cash crop and source of livestock feed in many developing countries. Maintaining stable yields of storage roots is a challenge for many sweet potato growers and in the tropics, sweet potato is often cultivated in low-fertility soils

In this PhD thesis, three experiments were used to investigate the morphological, physiological and symbiotic root characteristics of sweet potato under low P conditions. It was found that sweet potato showed little plasticity in the root traits typically found to enhance P uptake in key (non-tuberous) crops under low P conditions. However, other unexpected adaptation strategies were revealed including: i) tight regulation of internal P use allowing very low tissue P concentrations under a wide range of P supply, and; ii) an ability to manage rhizosheath microbial communities for benefit under low and high-P conditions. These findings will help to improve and stabilise storage root yield in both traditional subsistence agriculture and commercial high-input systems by selecting and breeding for improved cultivars.

This research is supported by Australia Award scholarship from the Australian Government.

How much chlorophyll is enough?

Project team: Adjunct Professor John Hamblin[1] (project leader; john.hamblin@uwa.edu.au), Dr David Bowran[4], Dr Dion Bennett[3], Dr Katia Stefanova[1], Mrs Freda Blakeway[2]

Collaborating organisations: [1]UWA; [2]SST; [3]AGT; [4]Yaruna Research

Chlorophyll provides the primary energy source for nearly all plant and animal species. The amount of chlorophyll in leaves differ between and within species. There has been very little work on whether there is an optimum level of chlorophyll in wheat that maximises crop growth and yield.

We identified 2 parental wheat genotypes where one variety (DBW10) on average had 58% more chlorophyll per unit area that the low chlorophyll parent (Transfer). Parental chlorophyll has been measured in 11 environments, including 8 years, 3 different plot types (single plants, short rows and field plots) and 4 sites (Shenton Park, Northam, Eradu and Gnopwangerup).

As chloroplasts are not transmitted in wheat pollen, these 2 parents were crossed in both directions in 2012 by Kevin Jose of Intergrain. The progenies were advanced to homozygosity in 2014 using rapid single seed decent by Professor Yan's group and by using double haploid technology by Ms. Broughton's group at DPIRD. We thank them for their help in this stage of the project.

In 2015, a total of 995 progeny, derived from the 4 combinations of cross direction and method of advance to homozygosity, were grown as space plants and their chlorophyll per unit area measured. From these 995 plants, 48 were selected for further examination.

Across the 10 environments used since 2015, chlorophyll content of the different lines and their 2 parents were consistently correlated across all 45 possible comparisons.

Besides chlorophyll, a range of agronomic characteristics have also been measured. Assuming that field trials are possible this season, 2020 will be last year that the 50 genotypes used will be grown. The relationships across environments and between characters measured will be documented and the seed and data made available to the Australian Grains Seedbank in Horsham.

This research was supported by SST.

Phenotyping root trait diversity of recombinant inbred lines and near isogenic lines of 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 organisations: [1]UWA

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Wheat (*Triticum aestivum*) is a major cereal crop contributing 28% of world cereal production in 2018/19 (FAO, 2019), and its demand is predicted to increase 50% by 2050. However, global wheat production is challenged by abiotic stresses, particularly heat, drought, salinity and biotic stresses such as diseases and pests. Australia is one of the major wheat exporting countries (65-75% of the production) but drought and high temperature stresses can cause up to a 43% decrease in wheat production.

Roots are directly associated with soil water and nutrient uptake, anchoring the plant in the substrate, interacting with plant-microbes, and storing resources. Consequently, roots are easily affected by abiotic stresses, particularly drought and nutrient deficiency, which ultimately affect yield potential. The functional efficiency of a root system depends on its root system architecture (RSA). Therefore, identification of root traits related genes from potential genotypes, and using them in genetic improvement of RSA is considered a useful tool for improving crop production. Recombinant inbred lines (RILs) and near isogenic lines (NILs) lines are pure lines commonly used for wheat development by breeders.

A glasshouse experiment was carried out to identify root trait variability in 141 genotypes of bread wheat, including 105 RILs (developed from Synthetic W7984× Opata 85) and 14 NILs using the semi-hydroponic phenotyping platform. Eight genotypes with contrasting root systems selected from a previous study were also used as checks. Significant variation in 12 root traits and 4 shoot traits were observed among the genotypes tested at the early growth stage (42 days after transplanting). RILs had significant variation in root length (RL), rooting depth (RD), root dry mass (RM), specific root length (SRL), root length intensity (RLI), number of nodal roots (NNR) and shoot dry mass (SM). The NIL pairs also varied significantly for the above traits along with root diameter (RDia). Significant positive correlation between RL, RD, RM, SM and RLI were identified. Genotypes with contrasting root system traits in both RILs and NILs have been selected for further studies. Using composite interval mapping (CIM) method of Windows QTL Cartographer2.5 (WinQTLcart2.5), major quantitative trait loci (QTL) of RILs for RL, RD, RM, SL and SM were identified. Further studies will validate the QTLs in the test population and identify root-trait associated genes and proteins from contrasting NILs.

This research was supported by RTP scholarship.

23: Wheat genotypes are growing in a semi-hydroponic system in the glasshouse, at UWA.

24: Rooting depth (cm) of genotypes (L-R: N8, N4, RIL30, RIL44) measured at final harvest.

Response of wheat genotypes with contrasting root system size to terminal drought stress

Project team: Ms Victoria Figueroa-Bustos[1] (project leader; victoria.figueroabustos@research.uwa.edu.au), Hackett Professor Kadambot Siddique[1], Assistant Professor Jairo Palta[1], Dr Yinglong Chen[1]

Collaborating organisations: [1]UWA

End-of-the season drought (or terminal drought) is one of the significant abiotic stresses affecting wheat yield in Australia. Soil water availability impacts directly on wheat yield and quality. In dry environments, access to soil water is critical for crops to maintain stable yields. The form and functions of a crop's root system are critical for accessing soil water to minimize water deficit during crop growth. A glasshouse pot experiment was carried out to examine the role of wheat root system size in conferring tolerance to terminal drought.

Wheat cultivars Bahatans-87 and Tincurrin, with large and small root system size respectively, were grown in 1.0 m deep PVC columns filled with soil in a glasshouse under well-watered conditions, until the onset of ear emergence (Z51) when a well-watered and a terminal drought treatment were imposed.

The results showed that the restricted water supply reduced stomatal conductance, leaf photosynthesis and transpiration rates faster in Bahatans-87 than in Tincurrin. Terminal drought reduced grain yield by 67% in Tincurrin, and 80% in Bahatans-87. The reduction in grain yield was due to reduction in grain number and grain size in Bahatans-87, and grain size in Tincurrin. Water use efficiency under terminal drought was lower in Bahatans-87 than in Tincurrin due to larger reduction on grain yield. The ratio of pre to post-ear emergence water use increased by terminal drought.

This study demonstrated strong association between root system size and phenology, leaf area and shoot biomass, and determined cultivar performance under terminal drought. Further studies to improve grain yield in water-limited environments should consider that association.

This research was supported by UWA and ANID (Becas Chile).

25: Wheat cultivars with contrasting root system growing in glasshouse facility, UWA.

Genetic and Genomic analyses of herbicide tolerance in bread wheat (*Triticum aestivum* L.)

Project team: Professor Guijun Yan[1] (project leader; guijun.yan@uwa.edu.au), Dr Ping Si, Hackett Professor Kadambot Siddique, Dr Roopali Bhoite

Collaborating organisations: [1]UWA (SAgE and IOA)

Wheat is Australia's largest grain crop and contributes to approximately 12% of world's trade. However, weed infestations cause serious reduction in wheat yields. Metribuzin is a broad-spectrum herbicide which allow effective weed management but narrow safety margin in wheat results in crop damage. Improving our understanding of the genetic and genomic basis for metribuzin tolerance will aid in development of new herbicide-tolerant wheats.

In December 2019, Ms Roopali Bhoite was conferred the PhD for this project. During this project, she:

- Identified new sources of metribuzin tolerance in wheat were identified,
- Conducted genetic studies (gene action and heritability) and rapid SNP discovery using wheat 90K iSelect SNP genotyping assay,
- Conducted QTL mapping to identify genomic regions contributing to metribuzin tolerance, and
- Conducted transcriptome analyses to identify key genes involved in regulation of metribuzin tolerance, genetic/signalling pathways, transcription factors, phytohormones, and gene-based EST-SSR markers related to photosynthesis and metabolic detoxification.

This research will provide valuable information to plant breeders and wheat producers in Australia and across the world.

This research was supported by Yitpi Foundation Research Awards (Plant Breeders' Rights Act), South Australia; Global Innovation Linkage program (GIL53853) from Australian Department of Industry, Innovation and Science; and Research Training program scholarship.

Durum wheat introgressed with TaMATE1B gene improved water use efficiency, grain yield and tolerance to Al^{3+}-toxic acid soil under later season drought

Project team: Hackett Professor Kadambot Siddique[1] (project leader; kadambot.siddique@uwa.edu.au), Dr Yinglong Chen[1], Adjunct Professor Jairo Palta[1,2], Dr Emmanuel Delhaize[2], Dr Lijun Liu[1,3], Dr Chunming Bai[1,4]

Collaborating organisations: [1]UWA; [2]CSIRO Agriculture & Food, Perth and Canberra; [3]Huazhong Agricultural University, China; [4]Liaoning Academy of Agricultural Sciences, China

Durum wheat (*Triticum turgidum*, tetraploid, AABB) has high grain protein content and market prices, but only occupies ~8% of the global wheat production area. In Australia, durum wheat production is limited due to its sensitivity to water deficit before or during anthesis, and aluminium toxicity under acidic soil conditions.

In Australia, durum wheat is cultivated in northern New South Wales, South Australia and western Victoria. Lack of spring rain lead to a moderate water-deficit stress for durum wheat at anthesis and grain filling. Subsoil acidity is a serious problem inhibiting root elongation and thus influencing water and nutrient uptake. Durum wheat is more sensitive to acid soils with a high Al^{3+} concentration, resulting in poor shoot and root growth and thus limited production.

By contrast, bread wheat (AABBDD, *Triticum aestivum*) exhibits a large variation in shoot and root growth on acid soils with toxic Al3+. Studies led by Dr Emmanuel Delhaize identified the major gene *TaALMT1* and minor genes such as *TaMATE1B* in bread wheat contributed to its tolerance to acid soils with high Al3+ concentration through encoding transport proteins that mediate the efflux of malate and citrate, respectively. Both genes for Al3+ tolerance from bread wheat have then introgressed into the durum wheat cultivar Jandaroi, which has been considered as an option for improving the tolerance of durum wheat to acid soils given the absence of genes for Al3+ tolerance in durum germplasm. Our recent studies discovered that (1) the introgressed lines Jandaroi–*TaMATE1B* showed greater tolerance to an Al3+-toxic acid soil than Jandaroi–*TaALMT1,* which differs from bread wheat where TaALMT1 is the more effective gene, (2) *TaMATE1B* gene enabled root growth and proliferation down an acidic soil profile with a high Al3+ concentration, which is important for Al3+ tolerance mechanism under subsoil acidity, and (3) under sufficient water supply, Jandaroi–*TaMATE1B* did not show significant promotion in shoot biomass and grain yield than Jandaroi–null (lack of *TaMATE1B* gene) (Pooniya *et al.* 2020. *Plant and Soil* 447: 73–84).

In 2019, a follow-up study investigated whether the improvements in root growth and proliferation in the introgressed Jandaroi–*TaMATE1B* can increase shoot biomass, grain yields and yield components than the non-*TaMATE1B* gene cultivar in deep columns packed with same acid soil (with high Al3+ concentration) from Merredin, Western Australia, under late season drought. Water stress was applied by withholding watering from the first awn emerged (Z49) to physiological maturity (Z91). The results showed that root growth and root proliferation in Jandaroi-*TaMATE1B* extended to 100cm deep under both well-watered and water-stress conditions, indicating an improvement in Al3+ tolerance, compared with Jandaroi-null which had limited root growth up to 60 cm. *TaMATE1B* gene increased leaf area and leaf biomass at first awn emergence (Z49, prior to drought imposed) by 28.6 and 25.7%, respectively, than Jandaroi-null. Under late season drought, Jandaroi-*TaMATE1B* increased grain yield by 42% (through increasing 1000 grain weight) than Jandaroi-null. The study confirms that introgression of the Al3+ tolerant *TaMATE1B* gene into durum wheat confers plant growth and drought stress tolerance, and increased grain yield by affecting the root proliferation into deep layers of Al3+ rich acidic soil, to access deep soil water when topsoil drying out during late season drought. This study provides evidence that the superior TaMATE1B gene appears to be advantageous under water-deficit, on acidic soils.

This research is supported by IOA, and China Scholarship Council of Chinese Ministry of Education.

26: Assessing photosynthesis of durum wheat cultivar Jandaroi introgressed with *TaMATE1B* gene grown in Al^{3+}-toxic acid soil under later season drought. L-R: Yinglong Chen, Chunming Bai and Lijun Liu.

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Comparisons of locally produced premium sulphate of potash and imported potash fertilisers on yield, quality of grain and soil biology

Project team: Hackett Professor Kadambot Siddique[1], Dr Zakaria Solaiman[1] (project leader; zakaria.solaiman@uwa.edu.au)

Collaborating organisations: [1]UWA (SAgE and IOA); [2]Australian Potash Limited

Supplying sufficient food for the rapidly growing population of the world presents one of the most significant challenges facing humanity at present. However, it is not only the quantity of food produced that should concern us, but its nutritional quality is also essential. Fertilisers offer the best means of increasing yield and maintaining soil fertility at an adequate level to ensure that good yields and quality. Macronutrients such as nitrogen, phosphorus and potassium are the major plant nutrients mostly used. Plants also require large quantities of sulphur, calcium and magnesium, and small quantities of some micronutrients. The intensely weathered nature of Western Australian cropping soils and the long history of potassium depletion by the cropping system has resulted in the increased incidence of potassium deficiency in broadacre crops. The effect of a single nutrient, like K in fertiliser, may depend upon how it is chemically combined in the fertiliser material, which affects both yield and crop quality. Because K fertilisers are obtained from natural products, they may contain substances other than K, such as S and Cl, and these substances may affect plant growth. Thus, choosing the right kind of potash fertiliser can be as important as applying the precise amount of potash to a crop. This project concerned with this choice and sought to answer the questions: What is a better form of potash? Here we are concerned mainly with the choice between the sulphate and the chloride.

Sulphate of potash (SOP) and muriate of potash (MOP) differ in their effects on plants in two ways: the anion accompanying the essential cation K has an impact on how cations behave and also directly affects plant metabolism, some plants being sensitive to Cl; and the S in SOP is itself a major plant nutrient, being a constituent of proteins.

The aims of this experiment were: (i) to compare the effect of SOP and MOP on yield and quality of both wheat and canola; and (ii) to investigate their role on nutrients uptake and the improvement of soil health.

In 2019, comparative effects of MOP and SOP on growth, yield and nutrition of wheat and canola were investigated in four different soil collected from Yuna, Kojonup, Southern Cross and Grass Patch of Western Australia. The experiment was laid out in a completely randomised block design under glasshouse conditions. Potassium fertilisers were applied at the rate of 60 kg K/ha of both sources along with the basal dose of 50 N/ha plus 50 kg P/ha. The treatments were: K0, K60-MOP, K60-MOP+Gypsum, K60-SOP. Both wheat and canola shoot growth and yield have responded similarly with SOP and MOP. But root growth was significantly higher with SOP relative to the MOP. Shoot K and S concentration and uptake increased with SOP compared to MOP. Grain yield of canola only increased in Southern Cross soil. Wheat grain K and S uptake were increased with SOP in Southern Cross soil. But in the case of canola, they were increased in all soils. Wheat protein concentration and protein yield were not increased with SOP and MOP application, but increased with SOP in three soils except Grass Patch in case of canola. MOP has an adverse effect on soil health (soil microbial biomass) but not for SOP, but this is observed only in Kojonup soil in wheat crop and two soils (Kojonup and Southern Cross) in case of canola crop.

Key findings:

- Both wheat and canola yield have responded positively to SOP and MOP;
- Shoot K and S concentration and uptake increased with SOP compared to MOP;
- Grain yield, grain K and S concentration and uptake were increased with higher rates SOP;
- Wheat protein concentration and protein yield were not increased with SOP and MOP application but increased in canola with SOP in three soils except Grass Patch soil;
- Soil health was impacted by MOP but not by SOP in both wheat and canola crops in some soils.

This research is supported by Australian Potash Limited.

27: Collaborators in the UWA glasshouse.

Use of a multispecies microbial inoculant to complement rock mineral fertiliser for wheat yield, nutrient uptake and rhizosphere microbial diversity

Project team: Mrs Salmabi Kayakkeel Assainar[1], Dr Zakaria M. Solaiman[1] (project leader; zakaria.solaiman@uwa.edu.au), Professor Lynette Abbott[1], Hackett Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA (SAgE and IOA); [2]Australian Mineral Fertilisers Pty Ltd

Fertiliser management practices alter soil microbial processes, including colonisation of roots by arbuscular mycorrhizal (AM) fungi and nutrient cycling by rhizosphere bacterial communities. AM fungi effectively increase the surface area of roots, and the soil microbial biomass contains a large pool of immobilised phosphorus (P) that is potentially available to plants. It is important to design and implement cost-effective, agro-environmental schemes that encourage landholders to adopt environmentally friendly farming practices, to meet environmental objectives at a minimum implementation cost. This includes effective use of soil microbial communities. Rock mineral fertilisers investigated here consist of a proprietary combination of various fine mineral ores, which include nutrients required by plants for growth and development. Scientific evidence about their effectiveness can be contradictory, which derives from inconsistent weathering rates and complex interactions with several factors such as mineral properties, soil microbial activity and climatic conditions. Microbial inoculation can stimulate mineralisation of rock mineral fertiliser to release nutrients for plant growth. While the idea of increasing agricultural yield without concomitant increases in fertiliser application is appealing environmentally, there are many unknowns about these bio-inoculant products (e.g. multispecies microbial inoculants). Microbial inoculants are potential components of agricultural management systems within the next 'green revolution' for more environmentally sound practices. Microbial inoculants that have defined and significant roles for their specificity when applied in various combinations have emerged as potential options for enriching soil health and plant growth. However, their efficacies under field conditions appear variable.

Microbial inoculants have potential to complement nutrient requirements for crop growth in agriculture. Therefore, in the first experiment, the comparative effect of a rock mineral fertiliser and a multispecies microbial inoculant on wheat growth and yield was investigated. The effects of two fertilisers (rock mineral and chemical) were compared with a multispecies microbial inoculant for growth and yield of wheat (*Triticum aestivum* L). The P in these fertilisers varied in solubility in water; P in the rock mineral fertilisers was lower in solubility than in the commercial chemical fertiliser. Microorganisms play an important role in the acquisition and transfer of nutrients in soil. For P, soil microorganisms are involved in a range of processes that affect its transformation and thus influence its availability (as phosphate) to plant roots. Despite an early reduction in plant growth, the microbial inoculant increased shoot growth and grain yield. At tillering, the proportion of roots colonised by AM fungi increased with the microbial inoculant and mineral fertiliser treatments but decreased with the chemical fertiliser treatments. At maturity, there were no treatment effects on the proportion of wheat roots colonised by AM fungi.

The second experiment investigated the effects of a polymer-coated rock mineral fertiliser combined with the multispecies microbial inoculant used in the first experiment. The polymer-coated rock mineral fertiliser with and without application of the multispecies microbial inoculant to seed increased shoot growth at tillering and maturity but root growth was only increased at maturity. Grain yield was lower for the un-coated fertiliser with microbial inoculation. In the absence of microbial inoculation, soil amended with polymer-coated fertiliser had lower residual soil P and potassium (K). Combined application of the microbial inoculant and this polymer-coated rock mineral fertiliser has potential to reduce fertiliser requirement while maintaining wheat productivity.

The third experiment evaluated the effect of the same multispecies microbial inoculant in combination with rock mineral fertiliser (bio-mineral fertiliser) augmented with rock phosphate (RP) and triple superphosphate (TSP) in terms of P utilisation efficiency (PUE) in wheat. The objective included determination of how much P from sources differing in solubility can be incorporated into the bio-mineral fertiliser for growth, yield and PUE without any detrimental effects on AM fungal colonisation. This was investigated under both glasshouse and field conditions. In the glasshouse experiment, bio-mineral fertiliser augmented with either RP or TSP increased shoot dry weights of wheat at both tillering and maturity. Application of 3.0, 6.0 and 9.0 % P as RP and 6.0% P as TSP produced significantly higher grain yields. In the field experiment, application of 6.0 and 12.0% P applied as RP and 3.0 and 9.0% P as TSP produced higher shoot dry weights than bio-mineral fertiliser alone. The bio-mineral fertiliser augmented with 3.0 and 6.0% P applied as either RP or TSP recorded the highest grain yields. Overall, PUE of the bio-mineral fertiliser, even when augmented with the two lowest levels of P (1.5 and 3.0% RP and TSP), was more effective than the bio-mineral fertiliser alone for wheat under both glasshouse and field conditions. Mycorrhizal colonisation at tillering under both glasshouse and field conditions declined with increasing P concentrations of TSP. The application of bio-mineral fertiliser augmented with low levels (up to 6.0%) of P from either source (RP or TSP) produced higher grain yield, P uptake and PUE. Thus, it was predicted that although this rock mineral fertiliser (bio-mineral fertiliser) does not have sufficient P for the effective growth and crop development, it can be augmented with a poorly soluble form of P as RP, or a more soluble form as TSP as a substitute.

While microbial inoculants are increasingly being considered as favourable components of agricultural management systems, their efficacy under field conditions may not reflect reported contributions under controlled glasshouse experiments. However, there is potential for a benefit from combinations of microbial inoculants and low fertiliser application rates or less soluble mineral fertilisers. Benefits may result from improved crop nutrient and water uptake, and also from water access associated with AM fungal colonisation during dry periods, especially in low P soils. Molecular advances in the last decade have now made it possible to track inoculation of single and multiple microbial inoculant genotypes and their diversity and functions into mainstream agroecosystems. However, despite the ability to assess the abundance of microbial inoculants in the rhizosphere soil environment, there is no universally adopted code of “best practice” regarding the inoculum selection and quality control. Therefore, the effectiveness and risk of microbial inoculation remain unclear for application in cropping situations.

This research was supported by Australian Government International Research Training Program (RTP) PhD Scholarship, UWA PhD Scholarship, Underwood Completion Scholarship, and Australian Research Council linkage grant (LP140100046).

28: PhD candidate Salmabi Kayakkeel Assainar with UWA’s mug for thesis submission celebration.

Growth of temperate perennial pasture grasses through microbial inoculant intervention

Project team: Mr Sangay Tshewang[1], Dr Zakaria Solaiman[1] (project leader; zakaria.solaiman@uwa.edu.au), Professor Zed Rengel[1], Professor Andrew Whiteley[1], Professor Kadambot Siddique[1]

Collaborating organisations: [1]UWA (SAgE and IOA)

Temperate perennial pasture grasses play a significant role in the supply of nutritive fodder and environmental restoration. However, the success of perennial pasture grasses is poor in low rainfall zones (<350 mm) and on marginal soils due to establishment problems. The Mediterranean-type climate in southern Australia, characterised by hot and dry summers, may also decrease their persistence due to their poor tolerance to summer drought. However, the poor establishment is often mitigated by supplying optimal nutrition through fertilisation.

In general, microbial inoculants have been evaluated widely in major cereals and legumes, particularly their significant impacts on N and P nutrition. However, similar information is limited in pasture grasses, even though microbial inoculants may be equally significant, particularly in Australia with large areas under pastures. More importantly, most of the agricultural soils in Australia are poor in major nutrients; hence, novel technologies that can increase fertiliser–use efficiency may bring enormous positive economic and environmental benefits. The project aimed to assess the effect of microbial consortium inoculant on the performance of five temperate perennial pasture grasses compared to rock mineral fertiliser treatment.

I 2019, five temperate perennial pasture grasses (cocksfoot, phalaris, tall fescue, tall wheatgrass and veldt grass) were evaluated under glasshouse conditions. The treatments included (i) control that did not receive any amendments, (ii) microbial consortium inoculant, (iii) combination of microbial consortium inoculant and the rock mineral fertiliser, and (iv) rock mineral fertiliser. Veldt grass produced the highest shoot and root growth while tall fescue yielded the lowest. Rock mineral fertiliser (with or without microbial consortium inoculant) significantly increased shoot and root biomass production across the grass species. The benefit of microbial consortium inoculation applied in conjunction with rock mineral fertiliser was significant regarding shoot N content in tall wheatgrass, cocksfoot and tall fescue. Shoot P and K concentrations also increased in the five grass species by microbial consortium inoculation combined with rock mineral fertiliser, in comparison with the control treatment. Arbuscular mycorrhizal colonisation decreased with rock mineral fertilisation (with or without microbial consortium inoculant) except in cocksfoot.

This research is supported by Research Training Program International Fees Offset Scholarship, Sir Eric Smart Scholarship for Agricultural Research, and SAgE research grant.

29: Effect of microbial consortium, rock mineral fertiliser with microbes, and rock mineral fertiliser on cocksfoot.

30: Effect of microbial consortium, rock mineral fertiliser with microbes, and rock mineral fertiliser on veldt grass.

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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 Pty Ltd; [3]Chinese Academy of Sciences; [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 yield wheat with good quality and adaptability in target environments.

A field trial of 150 wheat lines (including 120 Australian and 30 exchanged Chinese cultivars) has been conducted at the UWA Shenton Park Field Station. The field trial was arranged as 180 plants for each cultivar in three replicated blocks. The phenotypic data of yield and yield components (including plant height, thousand kernel weight and grain number) have been collected. Seeds produced from this trial have been sent to InterGrain, the Australian industry partner of the project, where they will be put in the field trials in 2020, at different locations in Western Australian. The phenotypic data obtained from the Shenton Park field trial are being associated with their genotypic data, and a manuscript is in preparation summarizing the results of this genotype-phenotype association analysis.

A total of 3903 cross population lines from 18 crosses between the exchanged Australian and Chinese cultivars have gone through quarantine. Around 1800 lines are chosen and grown for further advancement by UWA in the glasshouse, and by InterGrain in the field where a selection is conducted in each generation.

Field trials of exchanged wheat lines and cross population lines (crossed between the exchanged Australian cultivars and local elite lines) have been conducted in each of the global partner organizations in China, including trials in Inner Mongolia, Gansu, Beijing and Henan done by IMAAAH, GAAS, CAS and CAAS, respectively.

A project workshop was held at UWA, Perth, from 1-6 October 2019. All the global partners attended the workshop and project progresses and future plans were discussed. The project participants visited InterGrain Headquarter at Bibra Lake, and field trials at Dandaragan, Hyden and Dudinin in Western Australia.

This research is supported by Global Innovation Linkages Program by Commonwealth Department of Industry, Innovation and Science.

31: Wheat field trial at UWA Shenton Park Field Station.

32: Harvesting at UWA Shenton Park Field Station.

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

Project team: Mr 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 organisations: [1]UWA

Bread wheat (*Triticum aestivum* L.) is a major staple cereal crop, accounting for 50% of the world grain trade and approximately 20% of the calories consumed per capita globally. However, with increasing global warming, heat stress has emerged as a major problem in wheat affecting more than 40% of wheat growing regions. Heat stress during reproductive stage triggers senescence-related metabolic changes (which affect source-sink relationships) and causes failure of fertilization, smaller seeds and yield losses due to abnormal ovary development, reduced pollen tube growth and lower pollen viability. The use of heat stress tolerant cultivars in genetic studies revealed numerous genomic regions called Quantitative Trait Loci (QTL) for heat stress tolerance associated traits, but few major effect QTL, owing to the complex nature of heat stress tolerance. Little effort has been made to accumulate major QTLs for heat stress tolerance by recombination in breeding programs. Furthermore, most studies for heat stress screening are confined to anthesis stages and early grain filling (post-anthesis). However, few studies have screened for heat stress tolerance at meiosis stage. In addition, most studies on heat stress screening followed different temperature and duration regimes for heat stress, mostly prolonged exposure or extreme temperature, none of which reflects the field conditions. The study will test the effect of high temperature during meiosis on seed yield (seed number, size and weight) in different segments of the spike under conditions that are experienced in heat waves in the field.

This study aims to i) fine tune the screening methodology for heat stress tolerance during meiosis and fertilisation stages, and develop rapid measures of heat stress damage, ii) evaluate and develop molecular markers linked to major QTL, iii) study the potential additive effects of major QTL, and iv) identify new QTL/molecular markers/candidate genes via QTL-Seq approach.

This PhD project will develop a refined protocol for heat stress screening in wheat, particularly during meiosis and fertilisation stage, and will refine molecular markers for known heat tolerance QTLs and identify new candidate genes/QTLs for heat stress tolerance. This study will recombine several QTLs and evaluate improved heat tolerance in progeny with multiple QTLs. Heat tolerant wheat varieties will protect grain yield under predicted scenarios of global warming, thus improving food security and contributing to the national economy.

This research is supported by UWA International Fee Offset and University Post Graduate Award.

Use of Light Detection and Ranging (LiDAR) to detect late weeds in wheat crops

Project team: Dr Ken Flower[1] (leader; ken.flower@uwa.edu.au), Nooshin Shahbazi[1], Dr Michael Ashworth[1,2], Dr Nik Callow[1], Professor Hugh Beckie[2], Professor Ajmal Mian[1]

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

Weeds have a major impact on crop yields, and effective weed management plays a significant role in crop production. The majority of current weed control strategies are herbicide dominant 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, a number of 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.

This research will determine if LiDAR can be used to map late-season weeds in wheat fields. The aim of the project is to detect weeds above wheat crop fields using LiDAR and map their locations for weed management in the following season.

Two field surveys were carried out before crop harvest in 2018 and 2019 in the Western Australian Central Wheat-belt to assess the main late weed species growing above the crop. Weed species were identified and the height of both weeds and crops were measured. The results showed that the main weed species that grew taller than the crop at harvest time were *Avena fatua*, *Raphanus raphanistrum* and *Sonchus* spp.

In 2019, two trials were setup with the aim of understanding the LiDAR detection thresholds (above the crop) and its capability of distinguishing potential weeds. In the first trial, wooden rods of different dimeter and height were set out on a lawn at UWA and scanned with the LiDAR from different distances. This was to simulate weeds at different heights above a crop. In the second trial, conducted at the UWA Shenton Park Field Station, a plot of wheat was grown and weeds in pots (*Avena fatua* and *Sonchus* spp.) placed at different heights and positions in the crop before harvest. Scans were performed using a LiDAR attached to a motorised “4-wheeler”. The data is currently being analysed to determine optimal scanning parameters for the LiDAR, for weed detection above crops. The next step will be to take scans of farmers’ fields using the LiDAR.

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

33: The wheat plot was scanned using a LiDAR attached to a motorized “4-wheeler” at the UWA Shenton Park Field Station.

34: The present weed species were identified in the field and the weed/crop height was measured during the surveys at the Central Wheat-belt region of Western Australia.

Improving yield by optimising energy use efficiency

Project team: Dr Nicolas Taylor[1] (project leader; nicolas.taylor@uwa.edu.au), Professor Harvey Millar[1], Dr Elke Stroeher[1], Ms Sunday Tang[1]

Collaborating organisations: [1]UWA; [2]Australian National University; [3]The University of Adelaide; [4]CIMMYT, Mexico

The International Wheat Yield Partnership (IWYP; iwyp.org) was established to contribute to a G20 nations plan to strengthen future global food security. IWYP is a unique, international funding initiative to co-ordinate worldwide wheat research efforts. Globally, wheat is one of the most important staple crops, providing a fifth of daily calories. This project forms part of IWYP's plan to raise the genetic yield potential of wheat by up to 50%.

UWA researchers from the ARC Centre of Excellence in Plant Energy Biology, UWA School of Molecular Sciences and IOA form part of a team of Australian scientists that have been selected to address increasing the energy efficiency of wheat. More than 85% of the energy captured by plants is used in cell activities, some futile, meaning that only a very small amount of plant energy is realised as yield. Through a novel approach that combines cutting-edge mass-spectrometry techniques with traditional breeding the project will combine quantitative protein and metabolite measurements with growth studies and high throughput analysis of photosynthesis and respiration in order to screen elite wheat germplasm. Improving the ways in which energy is used and distributed within wheat plants has the potential to significantly increase their growth and crop yield.

During 2019, members of the team collected and analysed samples from field sites at CIMMYT and Ginninderra, ACT, and from glasshouse experiments carried out at the Plant Accelerator in Adelaide. Measurements of photosynthesis and respiration were carried out in a range of wheat varieties and collected plant material for analysis of proteins and metabolites by mass spectrometry.

This research is supported by IWYP and GRDC.

35: Dr Elke Stroeher analysing proteins and metabolites from wheat plants in the lab at UWA. Photo: James Campbell Photographics.

The Agricultural Research Federation (AgReFed)

Project team: Dr Nicolas Taylor[1] (project leader; nicolas.taylor@uwa.edu.au), Dr Ben Biddulph[2], Dr Nik Callow[1], Mr Brenton Leske[1], Professor Harvey Millar[1], Professor Tim Colmer[1]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]Centre for eResearch and Digital Innovation (CeRDI) at Federation University Australia; [4]CSIRO; [5]University of New England; [6]The University of Adelaide

Advances in farm technology have led to an increase in the collection of data by growers, agronomists, researchers and industry, with the potential to conduct advanced analysis techniques for better prediction. However, these data are not always findable, accessible, interoperable or reusable (FAIR). This leads to precious time lost in data cleaning and manipulation, or in the worst-case scenarios, poor science outcomes due to relevant data being ignored.

This project provides a federated system architecture that can incorporate diverse sources of data. This will ensure the benefits of increasingly available data are achievable, as each participant is being supported to make their data FAIR in a way that suits and serves them as well as the community, rather than being asked to conform to a single solution.

UWA and DPRID have provided an exemplar data set from the Dale research site that has been integrated into AgReFed (https://www.agrefed.org.au). Currently analysis of biological and yield data with time-series environmental data, sensor data, hyperspectral imagery data, and spatial data, is being carried out in collaboration with a machine learning team to investigate how new insight can be gained from the integration of these data types.

This research is supported by Australian Research Data Commons.

36: Yimin Wang and Anqiang Tang collecting canopy hyperspectral reflectance data at the DPIRD Dale research site.

Salt-tolerant wheat and pulses in smallholder farming systems in southern Bangladesh

Project team: Professor William Erskine[1] (project contact; william.erskine@uwa.edu.au), Professor Timothy Colmer[1], Dr Richard James[2], Dr MG Neogi[1]

Collaborating organizations: [1]UWA; [2]CSIRO; BARI; Bangladesh Agricultural University

Agriculture in southern Bangladesh centers on the annual cropping of monsoonal rice. Cropping in the dry cool season is limited and opportunities exist for more profitable dry season cropping by exploiting significant areas of fallow land between rice crops. This project asks - How can we increase small-holder household incomes through improved productivity and profitability of dry-season crops on non-saline land and, with pulses and wheat with improved salinity tolerance, on saline land in Southern Bangladesh?

The project is led by UWA and CSIRO as the key Australian partner on wheat salinity. In Bangladesh, BARI is the main agronomic research partner, while the socio-economics research is being undertaken by BAU and the Agrarian Research Foundation (ARF).

The context for practice change in dry season cropping in Southern Bangladesh is changing rapidly in response to migration, changes in water availability and policies, and climate change. To understand the situation, BAU found - in a baseline household survey of farming practices and livelihoods in both saline and non-saline affected areas - that farmers in saline areas had lower cropping intensities than their counterparts in non-saline areas and both lower productivity and profitability of major crops, leading to households in saline areas having lower annual income and food security.

ARF researched incentives and obstacles to dry season cropping in five Southern districts. Briefly, mungbean and grasspea are key dry season crops in Barisal Division. Recently, mungbean production increased substantially in Patuakhali and Barguna districts but decreased markedly in Jhalakati. Grasspea production has been drastically reduced throughout the Division, attributed by farmers to waterlogging due to excessive rainfall in November. The analysis showed that waterlogging-induced grasspea seedling damage can be attributed to slow drainage coupled with November rains.

To understand and evaluate production technologies for dry season cropping of pulses in saline-free land to increase productivity and profitability, BARI undertook agronomic research in Barisal Division of Southern Bangladesh during the 2018 and 2019 seasons. The mungbean sowing date of 15-30 January was found preferable to later sowing in 2018, and line sowing by machine yielded more than sowing by hand-broadcast and facilitated weeding in both years. In 2018, the average productivity of 14 demonstrations was 1372 kg/ha compared to 954 kg/ha on adjacent farmer-managed plots, indicating a yield gap of 418 kg/ha. In 2019, the demonstration (12) yields averaged 1144 kg/ha compared to 906 kg/ha in neighbouring plots, showing a yield advantage of 26% and a yield gap of 238 kg/ha. In the 2019 demonstrations, the average benefit-cost ratio was 2.12. Cowpea also looks promising in the coastal zone as an introduced line dramatically out yielded the local cowpea in both years.

To identify wheat germplasm with salinity tolerance adapted to Southern Bangladesh, a set of wheat lines were established to benchmark wheat germplasm. This benchmark set was evaluated at 10 field trials in 2017/18 and 6 trials in 2018/19, in southern Bangladesh. At most locations, an EM38 was used to characterise the distribution of soil salinity. Soil salinity increased throughout the season, with soil salinity levels similarly low at sowing, but doubling to moderate levels by anthesis. Site mean yield across field sites were generally high, ranging between 3.28 t/ha to 4.76 t/ha (except for 2.11 t/ha at Dacope) most likely indicating that the low to moderate salinity levels recorded throughout the season had little impact on limiting yield.

To identify germplasm of pulses with tolerance to salinity and water-logging stress, an integrated plan of research was agreed upon at the July 2018 abiotic stress methodology workshop. In Year 2, at UWA, germplasm of field pea and mungbean with tolerance to waterlogging at germination were identified by Ph.D. students. Systematic screening of the same mungbean germplasm set at BARI for waterlogging tolerance at the seedling stage was initiated.

This project is supported by an ACIAR grant and in-country research is co-funded by the Krishi Gobeshona Foundation.


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An integrated platform for rapid genetic gain in pulse crops

Project team: Dr Janine Croser (project leader; janine.croser@uwa.edu.au), Dr Judith Lichtenzveig, Dr Federico Ribalta, Professor William Erskine, Dr Maria Pazos-Navarro, Ms Simone Wells, Dr Richard Bennett, Ms Christine Munday, Ms Sabrina Tschirren

Collaborating organisations: [1]UWA; [2]Pulse Breeding Australia Breeding Programs; [3]Australian Grains Genebank

UWA00175 (July 2016-June 2020) delivered to the pulse pre-breeding and breeding community a robust platform for accelerated Single Seed Descent (aSSD) in the four major cool season legumes, faba bean, chickpea, lentil and field pea. Since the 2019 report, the UWA team has processed > 16,550 individuals across four domestic pulse species for SARDI, UoA, AgVic and NSWDPI based breeding programs. 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 herbicide tolerance (HT) screening of >550 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 has delivered 131 new *Cicer echinospermum (Ce)* accessions into Australia. UWA00175 var.2 (July 18-June 20) aimed to evaluate genetic compatibility of a subset of *Ce* accessions and chickpea to assess the potential for gene introgression from this wild species to the cultivar. We characterised eight *Ce* lines (using 13 'cultivar (cv.) x *Ce*' hybrids) and generated two populations to F3. We evaluated pollen viability and F1:2 seed production at F1 (n= 38 F1s and 9 parental lines in multiple repeats) and assessed the proportion of sterile F2 plants for the 13 'cv. x *Ce*' combinations. 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.

UWA00175 var.1 (Jul 18-Dec 20) 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. To achieve large numbers of F3 families, we produced 25 F1 hybrids and 6 clones per F1, harvested 4,507 novel cv. x wild F2s and sowed *c*. 300 *Cr* and 1,000 *Ce* F2-seeds per combination. The UWA Rapid Gene Introgression (RGI) platform, adapted from the aSSD research, has facilitated rapid delivery of F3 families, which will be ready by December 2020.

The team would like to acknowledge the contributions of our colleagues Leon Hodgson, Kylie Edwards, Theo Pfaff-Lichtenzveig, Yvonne Walker, Juan Perez, Elise Wells, Montana Walsh Baddeley, Maguelone Jaron and Mathieu Cluchier in the attainment of these research outcomes.

This research is supported by GRDC and UWA.

37: Faba bean pods developed under aSSD at UWA.

38: Rapid Gene Introgression (RGI) of wild genes into cultivated chickpea.

Phenology and resistance to pathogens in response to light quality

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

Collaborating organisations: UWA; Indonesian Endowment Fund

Plants experience a wide range of stress, often simultaneously, during their development that can limit productivity, including abiotic stress (e.g. light quality) and biotic stress (e.q. fungal attack). Many controlled environment based studies are designed to explore plant response to individual stress, and although they enhance our understanding, the results can be difficult to repeat under 'real world' conditions. Analysis of plant response to a combination of stresses deepens our understanding of the molecular network underlying the plant plastic adaptive potential. To this end, in 2019, Ms Purnamasari's PhD project focused on dissecting the genetics of plant defence response under contrasting light quality conditions relevant to disease epidemiology in the *Camelina sativa - Sclerotinia sclerotiorum* pathosystem. A recombinant inbred line population derived from a cross between a resistant accession and a susceptible one was grown under controlled conditions. Previous evidence suggested shade conditions, measured as red to far-red (R:FR) ratio, may lead to suppression of plant defence responses. Our results clearly demonstrate the trade-off between growth and defence in *C. sativa* RIL population both in seedling and adult stage. We identified two genomic regions associated with stem resistance each specific to either shade or normal condition, suggesting resistance under full light is compromised under shade. These QTLs were localised in the close proximity of genes that have been known to involve in traits contributing to defence mechanism and shade avoidance mechanisms. Our results provide evidence of the mechanism by which plants balance their growth and defence responses when grown under simultaneous abiotic and biotic stresses.

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

39: Study of cotyledon resistance to *Sclerotinia sclerotiorum* under shade-mimicking light.

40: Study of stem resistance to *Sclerotinia sclerotiorum* under shade-mimicking light.

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]

Collaborating organisations: [1]UWA; [2]Northern Australia Crop Research Alliance (NACRA); [3]King Saud University, Saudi Arabia; [4]DPIRD; [5]The University of Sydney

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 1. The development of robust intraspecies crossing methodology in both species 2. Controlled environment experiments to determine methods to grow these plants year-round, thus speeding the fixation of genes after crossing 3. Field trials to evaluate the value of new combinations 4. Use of sequencing data to determine hybridity. Highlights include the development of a practical and robust method for crossing (>90% success in chia) and year-round growth leading to the current production of recombinant inbred lines from a range of intraspecific crosses. 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.

41: A chia flower bud being emasculated ready for crossing.

42: Chia growing in the glasshouse at UWA. Plants are bagged to reduce chance of cross pollination between individuals.

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Sustainable Grazing systems

Theme leaders

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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 (R, D, E and 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:

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

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

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Annual Legume Breeding Australia (ALBA)

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

Collaborating organisations: [1]UWA (SAgE and IOA); [2]PGG Wrightson Seeds (Australia) Pty Ltd

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*).

A major highlight of 2019 was the official launch of the ALBA Joint Venture in October with a field day at the UWA Shenton Park Field Station, attended by around 70 dignitaries from UWA, research funding bodies, the pasture seed industry and farmers. This followed the appointment of pasture breeder Assoc. Professor Phillip Nichols and Senior Research Officer Bradley Wintle to the Joint Venture in January 2019.

Breeding highlights included the establishment 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 the establishment of Persian and arrowleaf clover breeding populations. Selection of subterranean clover breeding lines for low and medium rainfall areas and evaluation of balansa clover accessions also continued at the Shenton Park Field Station. ALBA also produced 10 kg of Breeders seed of subterranean clover cv. Tammin, under contract for Seed Force Pty Ltd.

In 2019, PhD student Gereltsetseg Enkhbat commenced her research project in association with ALBA titled "Diversity in waterlogging tolerance and other agronomic traits among subterranean clover ssp. *yanninicum*". Mohammed Abubakari also conducted the field work for his MSc project, titled "Diversity of balansa clover (*Trifolium michelianum*) for forage production" in association with ALBA. The results from both projects will be used to identify new parents and traits for future crossing programs.

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

1: The ALBA team among annual legume breeding plots at the UWA Shenton Park Field Station. Back row (left to right): Dr Derek Woodfield (General Manager Research and Development, PGG Wrightson Seeds) and Blair McCormack (Technical Services Manager, PGG Wrightson Seeds); middle row (left to right): John Stewart (General Manager – Australia, PGG Wrightson Seeds) , Assoc. Professor Parwinder Kaur (UWA), Assoc. Professor Megan Ryan (UWA) and Assoc. Professor Phillip Nichols (UWA); kneeling (left to right) Professor William Erskine (UWA) and Bradley Wintle (UWA).

2: ALBA subterranean clover breeding plots at the DPIRD Manjimup Research Station.

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

Project team: Gereltsetseg Enkhbat, 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 (SAgE and IOA); [2]Nagoya University; [3]ALBA; [4]PGG Wrightson Seeds (Australia) Pty Ltd

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 two other subspecies of subterranean clover. However, current cultivars of ssp. *yanninicum* comprise a narrow genetic base and the mechanisms of waterlogging tolerance among them are little understood. Additionally, ssp. *yanninicum* is shallow rooting with poor persistence on well–drained sandy soils in dry springs due to premature senescence.

In this project, we will examine agronomic traits for improved adaptation, productivity and resistance to abiotic stresses within the ~150 genotypes of ssp. *yanninicum* in the Australian collection 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 to identify if there is potential overcome weaknesses of current cultivars.

Over the last few decades historical rainfall has decreased, and annual rainfall is projected to further decline, over the cropping regions of southern Australia. Climate model projections suggest, for example, that drought will occur in the future almost four times more often in the south – west of WA than nowadays. The interactive effect of alternate wet and dry conditions adversely affect plant productivity and development, particularly in shallow–rooted species.

In 2019, we investigated genetic diversity for adaptation and production potential of ssp. *yanninicum* by measuring traits such as leaf size, petiole length, day to flowering and isoflavone contents. A total of 119 ssp. *yanninicum* (106 wild accessions and 13 cultivars), 26 ssp. *subterraneum* and 23 ssp. *brachycalycinum* were examined in this experiment. The experiment was conducted in a common garden at The University of Western Australia (UWA) Field Station at Shenton Park from May until November 2019.

Preliminary findings supported a part of hypotheses as displayed high genetic diversity for adaptation and production potential of ssp. *yanninicum* in important agronomic traits. Hypotheses related with relationships climatic /eco-geographic variables is still in process for evaluation as I am in middle of data analysis. Shortly, data collection is completed and data analysis is partially completed.

A second experiment conducted in 2019 was an examination of waterlogging tolerance among three subspecies of subterranean clover (ssp. *yanninicum*, ssp. *subterraneum* and ssp. *brachycalycinum*) to support a hypotheses that ssp. *yanninicum* have higher waterlogging tolerance and recovery ability than the other two subspecies of subterranean clover.

Results showed a significant variation in waterlogging tolerance within subspecies of subterranean clover and superior waterlogging tolerance in ssp. *yanninicum* was evidenced, agrees with several earlier findings. Results demonstrated, that larger the root system higher the tolerance in cultivars of subterranean clover, in particular when waterlogging is extended (r^2 =0.98; P<0.001). Greater response to waterlogging in ssp. *yanninicum* among the other subspecies of subterranean clover was associated with several traits such as higher chlorophyll content; lower increases isoflavone and anthocyanin concentration under waterlogging; higher constitutive porosity and enhanced porosity; lower reduction in stomatal conductance over the extended – waterlogging.

This research is supported by RTP, UPA, and Science Industry PhD fellowship.

3: *Trifolium subterraneum* L. ssp. *yanninicum* grown in the plot.

4: Three subspecies of subterranean clover grown in the glasshouse experiment.

Phase 2: 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], Professor Graeme Martin[1], Professor Phil Vercoe[1], A/Professor Caitlan Wyroll[1], Mia Kontoolas[1], Dr Jeremy Smith[1], Adjunct Professor Tim Watts[1], Mr Paul Sanford[2]

Collaborating organisations: [1]UWA (SAgE, School of Human Sciences and IOA); [2]DPIRD

Some old cultivars of subclover (*Trifolium subterraneum* L) contain high levels of oestrogenic compounds in their leaves. These are known to impact fertility of sheep – "clover disease". To better understand the prevalence of these cultivars during the 2019 growing season, we disseminated 230 free pasture kits with subclover ID sheets to producers, 103 kits were returned, a return rate of 45%.

Overall, our results confirmed that high oestrogen pastures are still very common in southern Australia and our previous estimates of 20% of pastures nationally is likely an underestimate. Our autopsy activities at a commercial farm and an abattoir show that there is likely a significant impact on animal health and flock fertility nationally.

Recent experimental work by UWA researchers has reinforced that environmental factors, such as waterlogging and phosphorus deficiency can significantly exacerbate the problem by increasing oestrogenic levels in the green leaves of subclover by up to three-fold.

In WA, we have been working closely with the DPIRD livestock group and their pathologists and towards upskilling of livestock veterinarians on oestrogenic clover and identification.

We have also submitted three papers to the Australian Association of Animal Sciences conference to be held in Perth in February 2021 All these will help to significantly raise the profile of the oestrogenic clover issue among animal scientist and veterinarians.

This project has led to a much greater awareness among producers, agronomists and, importantly, veterinarians of the impact of high oestrogenic clovers and clover disease. By its completion, it will redefine the whole clover disease complex.

This research is supported by MDC and FF2050.

5: Megan Ryan. Sampling for immunohistochemistry reaction with antigens for cellular receptors and for RNA.

6: Pasture sample returned with oestrogenic subclover: this one is pure Dinninup.

Environmental factors that increase phytoestrogens in subterranean clover

Project team: Professor Megan Ryan[1] (project leader; megan.ryan@uwa.edu.au), Dr Kevin Foster[1], Daniel Kidd[1], Eliott Reed[1]

Collaborating organisations: [1]UWA (SAgE and IOA)

Older cultivars of subterranean clover contain high levels of the phytoestrogen, formononetin (F). F is responsible for the oestrogenic effects in sheep which can cause severe health problems such as dystocia (difficult birth), decreased lambing percentages and blocked urethra in wethers leading to death. First described in the 1940s, this would later become known as 'clover disease'. Plant breeding programs since the 1970s have released low F cultivars with a considered 'safe' level of F, so by the 1990s the problem was thought to be resolved. However, older cultivars are very well adapted to the environment and removing them from the seed bank has proved difficult. The problem can be exacerbated by environmental factors such as phosphorus (P) deficiency and waterlogging, which are believed to increase levels of F in the plant. Therefore, this study examined the interaction of P deficiency and waterlogging on the level of F in a glasshouse experiment where plants were grown in mini swards. Five rates of P were used to create a P response curve, which enabled calculation of external critical P (i.e., the amount of soil P needed to give 90-95% of maximum yield).

P deficiency and waterlogging increased leaf F by up to 300%, but no significant interaction was found. These findings support previous recommendations that P be adequately applied to subterranean clover pastures to decrease oestrogenicity. Further research is needed to better understand environmental interactions which may make a pasture more potent to livestock.

This research is supported by AW Howard memorial trust, DPIRD Sheep Industry Business Innovation (SIBI) scholarship, MLA DC and UWA Future Farm.

7: Leaves of subterranean clover were 'clipped' so they could analysed for isoflavones using thin layer chromatography (TLC).

8: The mini swards used in the experiment and key project team members: Left to right: Dr Kevin Foster, Eliott Reed, Daniel Kidd.

BeefLinks Partnership Program

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

Collaborating organisations: [1]UWA; [2]Ternes Agriculture; [3]MLA; [4]MDC; [5]DPIRD; [6]West Midland Group; [7]Select Carbon; [8]Argaly (France)

BeefLinks is a newly formed collaborative research, development, extension and adoption (RDE&A) partnership involving Meat & Livestock Australia (MLA), MLA Donor Company (MDC) and The University of Western Australia (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. This will be achieved through a number of separate, but linked R&D projects and adoption activities coordinated under the umbrella of the BeefLinks Program. The research will focus on knowledge gaps that need to be understood in order to develop practical and robust management practices to improve the transition of animals from the pastoral zone (including grazed rangelands and pivots) into southern backgrounding systems, integrate the supply chain and build more certainty in year-round supply of compliant high value cattle. It will also include 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.

This research is supported by MLA, MDC, and UWA. MLA and UWA acknowledge the matching funds provided by the Australian Government through MDC, to support the research and development of the BEEFLINKS Program.

9: BeefLinks is a newly formed collaborative RDE&A partnership involving MLA, MDC, and UWA.

Do the antimethanogenic effects of Leucaena vary amongst species and accessions?

Project team: Mr Daniel Geurts[1], Professor Philip Vercoe[1] (project leader; philip.vercoe@uwa.edu.au), Dr Zoey Durmic[1], Dr Joy Vadhanabhuti[1], Dr Clinton Revell[2]

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

Leucaena is recognised as a feeding option that can reduce methane emissions from beef cattle and forms part of an approved methodology for methane mitigation under the federal governments Emissions Reduction Fund. Despite enormous potential for enhancing grazing production, leucaena is regarded as an environmental weed in northern Australia and planting leucaena pasture is not approved for on pastoral leases in the Kimberley and Pilbara regions of Western Australia. Therefore, a wide range of leucaena species/accessions are now being evaluated in DPIRD research to select elite breeding parents to develop sterile cultivar with high feed quality.

During the development of any new leucaena products, it is essential that the antimethanogenic benefits of leucaena are not inadvertently lost. This study aims to investigate; 1) fermentative traits with potential to reduce methane emissions intensity amongst commercial and experimental accessions of leucaena; 2) antimethanogenic effects in accessions with high fermentability that could be associated with tannin content; 3) variation in antimethanogenic effects amongst accessions within species and subspecies; and 4) whether the variability persists across developmental stages of the plants and locations.

Samples were collected from 48 single plants that represented the diversity of species and subspecies in the DPIRD collection. Samples were taken at vegetative stage (6-8 month old) and from regrowth in the following year. Samples of new leaves and old leaves were taken from plants of the same accession grown in glass house (South Perth) and in-field (Broome). The fermentability and anti-methanogenic effect were examined in an *in vitro* batch fermentation system.

Overall, there were significant differences between species/accessions of leucaena in fermentability and their antimethanogenic effects. Several accessions had the desirable combination of traits of moderate to high fermentability, with low to medium levels of methane. The presence of tannins influenced the methane production in some, but not all cases, where low methane emissions were observed. There was no difference between old and new leaves or where the plants were grown. Further investigations on other fermentative parameters (VFA, A:P and NH3) and nutritional parameters are underway, but it is clear that there is enough diversity in fermentability and antimethanogenic properties to be useful in a breeding programme.

This research was supported by UWA, DPIRD, and Agribusiness Regional Connect Scholarship.

10: Leucaena growing in the glasshouse.

Fit for purpose biochar to improve efficiency in ruminants

Project team: Dr Zoey Durmic[1], Dr Xixi Li[1], Professor Joy Vadhanabhuti[1], Professor Philip Vercoe[1] (project leader; philip.vercoe@uwa.edu.au)

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

In Australia, the majority of cattle and sheep are produced extensively on high fibrous diets, which are associated with up to 60% more energy lost as methane when compared to high grain diets. This energy could be conserved to improve productivity rather than lost as greenhouse gas. Ruminant production systems need novel products and innovative strategies to reduce ruminal methane emissions, improve efficiency and overall profitability. Biocarbon is a cellulose rich pyrolyzed biomass. There is anecdotal evidence that the live weight of Angus-X cattle was improved when fed biocarbon. Recent research suggests biocarbon products vary in their effectiveness in reducing methane production and altering end products of fermentation. There is a huge diversity in biocarbon types and a significant gap in knowledge about the mechanism and specific physical characteristics of biocarbons that is associated with improving rumen efficiency.

This project aims at screening, quantifying and validating the effects of biocarbon on animal productivity and also at modifying and generating the best biocarbon that is suitable for feeding animals.

To date, we have:

1. Compared and documented the effects of different biocarbon types on rumen efficiency in the *in vitro* fermentation.
2. Identified key characteristics of the most effective biocarbon for reducing ruminant methane production.
3. Selected effective biocarbons and confirmed their antimethanogenic effect can last over 14 days in the continuous in vitro fermentation system (Rusitec).
4. Performed microscopy analyses to reveal detailed chemical, physical and microscopic properties of the biocarbon that were tested in the Rusitect.
5. Designed and generated new generation of biocarbon that can effectively reduce ruminal methane production.

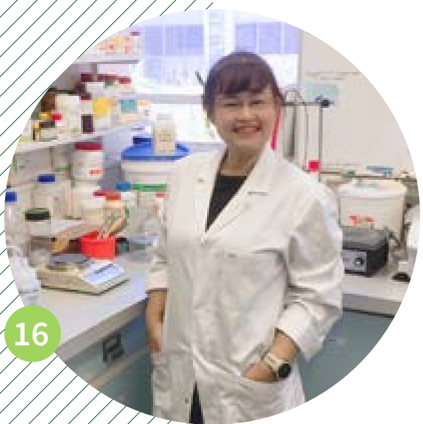
We are in the process of planning the persistency and dose effect of new generation of biocarbon in the coming Rusitec experiment. An animal experiment will be conducted later this year by our collaborators to identify an effective dose of biochar that can maximize productivity and minimizes emissions from livestock systems.

Overall, we have confirmed that biocarbon can be custom designed to vary their effects on rumen fermentation. Our finding will provide crucial data to quantify the effects of biocarbon on animal productivity and enteric methane emissions.

This research was supported by Meat and Livestock Industry

11: Biochar at Dough Pow.

12: Cattle eating biochar.



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

Project team: Mr Shamshad Ul Hussain[1], Adjunct Professor Johan Greeff[2], Professor Graeme Martin[1], Associate Professor Parwinder Kaur[1], Dr Alfred Tay[1]

Collaborating organisations: [1]UWA (Marshall Centre and IOA); [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 parasites, leading to huge economic losses.

In Western Australia, especially in winter rainfall zones, Merino sheep suffer from diarrhoea caused by gastrointestinal worms, particularly *Teladorsagia circumcinta* and *Trichostrongylus colubriformis*. Since the 1990s, Dr Johan Greeff and his colleagues have been breeding sheep for resistance to these worms and have produced the Rylington Merino flock, the most worm-resistant sheep in the world. However, among the resistant animals, exposure to even a few worms leads to severe diarrhoea.

I am investigating this problem at gene level, using transcriptomics, to compare sheep that are resistant to infection with no diarrhoea with sheep that are resistant but still develop diarrhoea and sheep that are fully susceptible to worm infection.

My studies involve RNA extraction and sequencing, followed by data analysis using the Pawsey Supercomputer. I expect to find a set of genes with various biological functions that explain why some worm-resistant animals develop diarrhoea and others do not.

However, we need to remember that worm infection of sheep involves two genomes – the sheep genome and the worm genome. Therefore, in the second part of my project, I will assemble the genomes of *Teladorsagia circumcinta* and *Trichostrongylus colubriformis.* I will use chromosome-length genome assembly with a unique approach that includes DNASeq and Hi-C sequencing. I have completed the short-read DNASeq sequencing and generated a draft assembly using w2rap-contigger. The Hi-C sequencing is still under process, and results will be combined to use in 3D-DNA pipeline and Juice box assembly tools to finish a chromosome length genome assembly. The genome assembly is crucial in understanding the biology of these economically important parasite species.

By understanding the interactions between the sheep and worm genomes I hope to able to offer a pathway towards and industry-wide, genetic solution to worm problem.

This research was supported by University of Agriculture Faisalabad (Pakistan), SAgE, Australian Wool Innovation, DPIRD.

13: L-R Mr Shamshad Ul Hussain (PhD student), Ms Prapawan Krommarin (PhD student), Dr Erwin Paz Muñoz (Adjunct IOA).

14: RNA extraction prep by Mr Shamshad Ul Hussain.

Does the gut microbiome help us explain worm resistance in sheep?

Project team: Dr Erwin Paz Muñoz[1] (project leader; erwin.paz@uwa.edu.au), Professor Graeme Martin[1], Dr Eng Guan Chua[3], Dr Alfred Tay[1], Dr Shimin Liu[1], Adjunct Professor Johan Greeff[2], Dr Dieter Palmer[2]

Collaborating organisations: [1]UWA (Marshall Centre and IOA); [2]DPIRD

Parasitic gastro-intestinal worms are a major problem that affects the sheep industry worldwide. The intensification of grazing systems has increased the ingestion, by the host, of the free-living stages of the worm life cycle and, to make matters worse, the worms have become resistant to the medications that have been used to control them for decades. In WA, DPIRD has been breeding sheep that are resistant to gastro-intestinal worms for 25 years using faecal worm egg count as the selection criterion. We are still trying to understand how the selection has worked … what has changed in the sheep?

In recent times, we have been intrigued by the possibility that the microbiome in the sheep's gastrointestinal tract may contribute to resistance and susceptibility. This led to a collaboration with *The Marshall Centre for Infectious Diseases,* taking advantage of their history at the forefront of infectious disease identification and surveillance, diagnostics and drug design, and transformative discovery. We compared the 10 most resistant sheep to the 10 most susceptible, looking at the gut content in the rumen, abomasum, duodenum, jejunum, ileum, caecum, colon and rectum. By studying the DNA, we could analyse the populations of microbes and test whether they had been changed by genetic selection.

We saw significant differences in diversity in the duodenum, with seven microorganism species showing major changes. Twenty-four biochemical interactions ('KEGG pathways') were affected, suggesting major changes in the metabolism of carbohydrates, lipids, nucleotides and amino acids in the resistant group.

We now need to understand how these microorganisms affect resistance and susceptibility to worms. The worm resistant ewes and rams used for this investigation are a world-unique resource that is revealing how the gut microbiome plays a critical role in worm-control strategies.

This research was supported by UWA, DPIRD, and Marshall Centre.

15: Erwin Paz (left, in front of the computer) presenting his preliminary results at *The Marshall Centre for Infectious Diseases*.

The immune system in Merino sheep selected for resistance to nematode infection and breech flystrike

Project team: Mrs Prapawan Krommarin[1], Professor Graeme Martin[1] (project leader; graeme.martin@uwa.edu.au), Dr Alma Fulurija[1], Dr Dieter Palmer[2], Dr Johan Greeff[2], Dr Shimin Liu[1]

Collaborating organisations: [1]UWA; [2]DPIRD; Faculty of Health and Medical Sciences, Infection and Immunity; Australian Red Cross Blood Service QLD

In ruminant livestock, gastro-intestinal helminths (worms) reduce animal productivity and increase management costs. The worms also cause diarrhoea and, in Merino sheep, the diarrhoea accumulates in the 'breech', attracting blowflies leading to flystrike. Moreover, around the world, the worms are becoming increasingly resistant to anthelmintic medication.

After 20 years of genetic selection, the Department of Primary Industries and Regional Development (DPIRD) has produced a flock of Merino sheep that is highly resistant to helminth infection. The effectiveness of this approach is very clear, but unfortunately, some of the resistant animals still have diarrhoea, perhaps because they have become 'hypersensitive' to even a small number of worms. 'Hypersensitivity' is similar to an allergic response and undoubtedly involves the immune system, and therefore blood-borne antibodies or immune cells.

To find a solution to this problem, we identified the components of the immune system in sheep that explain the hypersensitivity for breeding sheep predisposition to diarrhoea. The original selection for worm resistance was based on assessment of the faeces of sheep, measured as the number of worm eggs (faecal worm egg counts; FEC) and faecal consistency score (FS). Our new data suggest the we should add a trait directly linked to immunity. We have found clear associations with the blood concentrations of immunoglobulin E, tumour necrosis factor alpha (TNFα) and number of eosinophils. It seems likely that immunity-based traits can be combined with FEC and FS to improve the selection process, so we can avoid hypersensitivity diarrhoea while breeding for worm resistance.

This research was supported by UWA, DPIRD, and AWI.

16: Prapawan Krommarin conducted experiments at the DPIRD laboratory.

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Can *Khaya senegalensis* improve gut health in sheep?

Project team: Suyog Subedi, Professor Graeme Martin, Professor Philip Vercoe (project leader; philip.vercoe@uwa.edu.au), Dr Zoey Durmic, Dr Stephanie Payne, Dr Andrew Richard Williams

Collaborating organisations: UWA; CSIRO; DPIRD; Bioactive Laboratories; University of Copenhagen

Plant products have been used throughout history to treat human and animal diseases. Evidence shows that some secondary plant compounds can be used as a natural alternative to synthetic drugs, and there is a growing trend to validate their efficacy by measuring their bioactivity and identifying the molecules responsible for the activity in phytochemical studies. There is evidence from previous studies that the tree *Khaya senegalensis* has a range of bioactive properties. For example, extracts from this plant can affect Gram-positive and Gram-negative bacteria in humans and may have anthelmintic properties that could be used to combat gastrointestinal worms of sheep. However, there is no information about the chemical nature of the active compounds responsible for the effects or the mechanisms of action involved. It is possible that *K. senegalensis* could be used to manage major pathogenic gut bacteria in sheep and/or lactic acidosis in the rumen, but this has never been investigated. In this project, I will isolate and identify compound(s) from *K. senegalensis*, study their anthelmintic properties, and try to elucidate the underlying mechanism of action. I will also examine the effects of whole plant extracts as well as particular compounds, for their effects on major pathogenic strains of gut bacteria and the potential to manage ruminal lactic acid formation. This combination of studies will allow an assessment of the potential of *K. senegalensis* to be used to manage the general gut health of sheep.

I have generated a number of extracts of *K. senegalensis* using various solvents. These extracts have been generated from plant samples pooled from a number of trees as well as from individual trees. The results from the extracts generated from pooled samples were more variable and less active in egg-hatch assays used to test anthelmintic activity. In contrast, egg-hatch assays using the extracts from individual trees showed strong activity. When HPLC and GCMS analyses were used to profile the samples, there were clear differences in molecular composition among samples from different trees. We established a collaboration with Dr Andrew Williams, at the University of Copenhagen, who is a world leader in this field and has a laboratory with the capacity for automated high throughput screening of compounds for anthelmintic activity. I successfully applied for a Mike Carroll Travelling Fellowship that has enabled me to visit Dr Williams' laboratory and complete an extensive screening of the extracts and fractions I have collected from *K. senegalensis*

This research is supported by UWA and Bioactive Laboratories.

17: Fractions from Khaya leaf extract.

18: Khaya fractions subjected to egg hatch assay.

Comparison of the rumen epithelium of high- and low- methane emitting sheep by transcriptome and proteome analysis

Project team: Mr Umair Hassan Khan[1], Professor Philip Vercoe[1] (project leader; philip.vercoe@uwa.edu.au), Professor Hutton Oddy[2], Dr Jude Bond[2], Dr Nick Hudson[3], Dr Brian Dalrymple[1]

Collaborating organisations: [1]UWA; [2]DPIRD-University of New England, NSW; [3]University of Queensland; University of Agriculture, Faisalabad, Pakistan

The rumen is often seen only as a site of fermentation, but its epithelium is responsible for many other critical functions, such as the absorption, transport and metabolism of nutrients. The energy metabolism of the rumen epithelium changes in response to changes in dietary energy intake and composition. This is mostly because of changes in tissue mass rather than changes in metabolism per unit epithelial mass. We would expect these responses to be mediated by alterations in gene expression, but the activities of the major genes have not been mapped to, for example, quantitative changes in protein abundance. This relationship is important because protein abundance accounts for the phenotypic variation in methane emission. Similarly, there have been few studies of the regulatory proteins in the rumen epithelium that respond to changes in the physiological status of the animal.

In previous work with sheep, a proteomic dataset from rumen epithelium cytosol and a transcriptomic dataset from the rumen wall were used to identify proteins and genes that were expressed differentially (DE) between high methane emitters and low methane emitters. The DE proteins and DE genes were studied separately and there appeared to be no relationship between them. This outcome was counter-intuitive and might be explained by data noise or differences in the cellular composition of the samples used for the separate proteomic and transcriptomic analyses.

To clarify this situation, more samples of rumen epithelium proteins and the membrane sub fraction have now been analysed. Proteomic comparisons suggest that proteins positively DE in the rumen epithelial membrane were significantly more likely to be positively DE in the rumen epithelial cytosol. Similar relationships were evident for negatively DE proteins. However, unlike the sign of the DE, the values of the DE were not significantly related. The rumen epithelium cytosol and membrane proteins were subdivided, using gene expression cluster analysis, into two groups: i) genes/proteins preferentially expressed in the epithelial or muscle components of the rumen wall; and ii) the remaining generally expressed genes/proteins. The general proteins/genes did not differ between high-emitting and low-emitting animals in any dataset. In contrast, the epithelial proteins were significantly more represented in the high-methane animals (i.e., positively DE) and the muscle proteins were significantly more represented in low-methane animals (i.e., negatively DE). A transcriptomic analysis of the full-depth rumen wall dataset presented a similar result for the genes.

In conclusion, the genes and proteins in the epithelium might be able to explain variation in the amount of methane produced by sheep, with high-methane animals showing a lower expression of muscle genes and proteins, and a higher expression of genes and proteins in the epithelium. However, this conclusion was not supported by the physical measurements, leaving further questions to be addressed.

This research was supported by MLA.

19: Measuring the methane produced by sheep.

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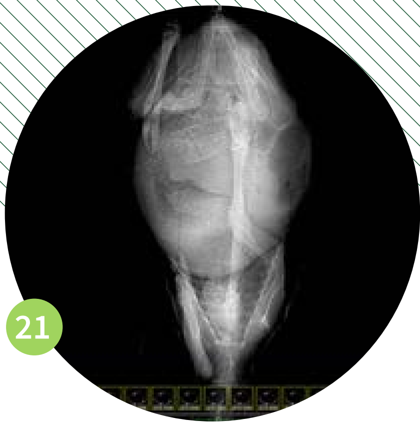

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‘Better doers’ – The key to selecting nutrient-efficient livestock

Project team: Mr Umair Hassan Khan[1], Professor Philip Vercoe[1] (project leader; philip.vercoe@uwa.edu.au), Professor Hutton Oddy[2], Dr Jude Bond[2], Dr Nick Hudson[3], Dr Brian Dalrymple[1]

Collaborating organisations: [1]UWA; [2]DPIRD University of New England, NSW; [3]University of Queensland, Brisbane; University of Agriculture, Faisalabad, Pakistan

In this project, we are testing whether biomarkers can be used to predict methane emissions in sheep. The biomarkers of interest are proteins that are involved in the metabolic processes controlling nutrient use in the rumen epithelium cells, and that differ between sheep showing low- and high-emitting phenotypes. However, in the studies that revealed these candidate biomarkers, all the sheep were fed the same diet, which was effectively a basal diet that provides maintenance requirements.

Our first step was to phenotype wethers on the basis of residual feed intake (RFI), by feeding them *ad libitum* with the base diet for 60 days. We also measured traits that underpin nutrient use efficiency and therefore reflect the retention of feed energy in the body: liveweight, average daily gain, gains in muscle, fat and bone. This data was entered into a simple equation that provides an estimate of the proportion of intake energy retained:

RFI = energy retained (LWT, ADG, muscle, fat and bone gain) – energy lost (faeces, urine, gas)

To obtain the data for muscle, fat and bone, we used CT scans of the whole sheep body so we could assess carcass composition *in vivo*. This procedure is difficult because it is labour-intensive and time-consuming, but the major benefit is that we can obtain real data on body composition in live sheep, without needing to resort to serial post mortems, with simultaneous ethical benefits. The CT scan images are a rich source of information, providing data that can be used later to provide a complete picture on the distribution of nutrient energy in the body and where it is deposited. For example, data become available for rumen volume, organ size and weight, and intramuscular, visceral and subcutaneous fat.

The second stage of the project tested the hypothesis that proteins in the rumen epithelium differ quantitatively between phenotypes for nutrient efficiency (RFI) and that this relationship will be most evident when sheep are fed different diets. The RFI phenotype explained a significant amount of the phenotypic variation in a large flock. This observation underpinned an experiment in which we tested whether nutrient transporters, found in the cell membrane of the rumen epithelium, differ quantitatively between low and high phenotypes in RFI, live weight gain and fat gain, when the sheep are fed two different diets. We profiled many proteins in the rumen epithelium so we could explain the phenotypic differences in terms of biological processes.

Our results have revealed two possible mechanisms of nutrient use efficiency:

1. Variation in the intermediary metabolism of nutrients in the rumen epithelium and therefore in the subsequent absorption of those nutrients into the blood stream;
2. Variation in the abundance of membrane-bound nutrient transporters in the rumen epithelium.

This research is supported by MLA.

20: Mr Umair Hassan with a CT scanner.

21: CT scan of sheep.

Investigating the mechanism of methanogenesis inhibition by plant-based essential oil compounds

Project team: Muhammad Shoaib Khan[1], Dr Zoey Durmic[1], Dr Parwinder Kaur[1], Professor Graeme Martin[1], Professor Philip Vercoe[1] (project leader: philip.vercoe@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]University of Agriculture, Faisalabad, Pakistan; [3]WA Human Microbiome Collaboration Centre, Curtin University

Climate change is one of the most challenging issues confronting society and one of the main causes is the emission of greenhouse gasses into the atmosphere. Methane is a potent greenhouse gas and is a natural end-product of fermentation in the rumen. In Australia, ruminant livestock are the major source of methane emissions and represent nearly 12% of total agricultural greenhouse gas emissions. This methane is also considered an inefficiency in animal production because it can represent a 2-12 % loss of the feed energy consumed by the animal. Several strategies and approaches to mitigate methane in ruminants are being explored and identifying anti-methanogenic plant secondary compounds that could be used as feed additives is one strategy that might provide a sustainable solution. Our research group has screened a number of plant sources and identified compounds within essential oils that are effective in reducing methane and increasing volatile fatty acid production, the main energy source for ruminants. Two compounds have been purified (C, and D-L) that are responsible for the effects, but we do not understand their mechanism of action. We used a continuous culture *in vitro* system that simulates the rumen (Rusitec) to explore the mechanism of action of these compounds on rumen fermentation and changes in microbial ecology.

We collected samples from the Rusitec experiment and used molecular tools and bioinformatics to analyse them to determine what effect the compounds had on microbial profiles. My results show that *Prevotella spp., Lactobacillus spp.* and *Streptococcus spp.* were abundant and there was more bacterial diversity observed in the treatments (when C and D-L were present) compared to the control. We are now looking at the increased bacterial diversity in more detail, as well as the changes specifically to the methanogen species, to help explain the improved fermentation parameters we found in the treatment groups. The final piece of the puzzle will be to complete an analysis of gene expression in these samples to identify the genes that have been targeted by the compounds, which will help explain how these compounds are affecting the microbial ecology and the end-products produced. These results will influence how we use these compounds as feed additives to have the greatest impact on methane production from ruminants without compromising productivity.

This research is supported by UWA.

22: Analysing rumen-bacterial amplification plots from RUSITEC samples.

23: Preparation for loading of bacteria 16S rRNA library for massive parallel sequencing on illumina MiSeq platform.

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Feeding goats with heated linseed grain improves fatty acid content of meat

Project team: Dr Xue Wang[2], Professor Sumei Yan[2] (project leader; yansmimau@163.com), Dr Qi Wen[2], Dr Shulin Liu[2], Dr Juan Zhang[2], Dr Yang Yu[2], Professor Binlin Shi[2], Dr Xiaoyu Guo[2], Dr Yanli Zhao[2], Professor Graeme Martin[1]

Collaborating organisations: [1]UWA; [2]College of Animal Science, Inner Mongolia Agriculture University

There is an imbalance in the proportion of fatty acids (FAs) in the typical western diet, with a high ratio (n6:n3) of n-6 poly-unsaturated FAs to n-3 poly-unsaturated FAs (PUFA). In humans, additional dietary n-3 PUFA provides more of the critical substrate (α-linolenic acid; C18:3n3) for synthesis of the functional n-3 long-chain PUFAs (LC-PUFAs). The outcome is improvements in immune function, blood pressure, cholesterol and triglyceride levels, and cardiovascular function.

An important source of n-3 PUFA for humans is meat from ruminants, but the amount present in the meat depends on the diet of the animals. For example, the meat concentrations of n-3 PUFA and n-3 LC-PUFA are lower, and the n6:n3 is higher, in goats fed a total mixed ration than in those fed on pasture, apparently because the pasture-fed goats consume more C18:3n3.

The n-3 PUFA content in meat can be increased by including linseed oil (LSO) in the diet of the animals, but some advantage is lost because the C18:3n3 is hydrogenated in the rumen. A very attractive alternative is to use linseed grain that has been heated to 130 °C for 20 min. This treatment increases the flow of the C18:3n3 out of the rumen into the rest of the digestive system where it can be absorbed, leading to an increase in the concentration of n-3 LCPUFA in adipose tissue.

We have now completed a series of studies looking into the mechanisms involved in the response to heated linseed grain. First, we studied the rumen bacteria that hydrogenate C18:3n3 and found that heated linseed reduces the relative abundance of Ruminobacter and increases the relative abundance of Prevotellaceae_UCG-001 and Fretibacterium. These changes explain the decrease in hydrogenation of C18:3n3 that eventually leads a lower n6:n3 in meat.

Second, we studied the expression of genes that control fat metabolism in the goat. Dietary FAs are converted by the liver into LC-PUFA that are secreted into the blood, from where they are taken up by adipose and muscle tissues. In goats, the inclusion of heated linseed in their diet stimulates the expression of genes in adipose tissue that increase n-3 LCPUFA synthesis and the amounts of C22:6n3, C18:3n3 and n-3 PUFA, thus decreasing the n6:n3 ratio.

In conclusion, through various processes, feeding heated linseed grain leads to the deposition of more C18:3n3 and C22:6n3 in goat meat. Other studies suggest that the same applies to sheep meat. Our findings provide insight into the use of different dietary sources of α-linolenic acid to manipulate FA composition in ruminant products, from which we can expect benefits for human health.

This research was supported by National Key R&D Program of China (Project 2017YFD0500504), National Natural Science Foundation of China (Project 31760685), and China Scholarship Council (CSC).

24: Dr Xue ('Snow') Wang, of the College of Animal Science, Inner Mongolia Agricultural University, working in the laboratory at UWA with Assoc/Prof Shimin Liu.

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.

Machine learning to improve water management in dryland agricultural ecosystems

Project team: Assoc Prof Sally Thompson (project leader; sally.thompson@uwa.edu.au)[1], Dr Octavia Crompton[2]; Anneliese Sytsma[2]

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

Machine learning is an application of artificial intelligence, which provides computers with the ability to learn without explicit programming. A new machine-learning tool was developed that will improve the management, restoration and irrigation of rangeland areas used for grazing. The tool models surface water flows in dry environments with patchy vegetation cover, and is suited to environments where the amount of rainfall exceeds the absorption capacity of the soil resulting in the excess water flowing over the land.

The new machine learning technique is an advancement over existing tools, as it is much faster than previous models and was designed to handle diversity in various environments. This approach allowed the researchers to speed up predictions by a factor of 15,000 and avoid direct simulation with a physics-based model, which is slower and computationally expensive.

The water model is currently being included in ecological simulations of long-term desert vegetation growth and spread, meaning that the impact of storm-scale processes on ecological processes over the long term can be predicted for the first time. The findings have significant implications for agricultural and natural systems in Australia and worldwide, e.g. to help environmental designers limit soil erosion in rangeland environments and agricultural systems, and minimising degradation risks in drylands. It also has applications in urban settings, where waterproof surfaces, like pavement, generate runoff and flood risks.

This research is supported by the Binational Israel-US program of the US National Science Foundation.

1: Overland flow in a patchily vegetated landscape, in Ocotillo, California.

Mapping moisture in variable-textured soils of Western Australia by non-invasive methods

Project team: Miss Hira Shaukat[1], Dr Matthias Leopold[1] (project leader; matthias.leopold@uwa.edu.au), Dr Ken Flower[1], Dr Craig Scanlan[1,2], Dr Liz Barbour[1]

Collaborating organisations: [1]UWA (SAgE and IOA); [2]DPIRD; CRC Honey Bee Products

Western Australia (WA) has highly variable soils and the climate is currently changing towards less winter rainfall. Decrease in soil water is one of the main production constraints in a rainfed agriculture systems. Therefore, knowledge of spatial distribution of plant available soil moisture is one of the most important yield and profit-determining factors. However, rapid and precise quantification of hydrological processes in crop fields is challenging because soil moisture is dependent on interacting soil properties, which vary greatly.

An electromagnetic induction (EMI) instrument (Dualem-1HS) was used to map soils at sites in the Wheatbelt region, including Cunderdin, York, Pingelly (UWA Farm Ridgefield) and CRC for Honey Bee Products sites at Badgingarra, Kukerin, Wilga. These soil-mapping surveys were completed over both dry and wet conditions in 2019. This non-invasive instrument takes apparent electrical conductivity (ECa) data at different depths and provides a relatively rapid way to cover large areas. This technology is being coupled with electrical resistivity tomography (ERT) to measure soil moisture status for a full season at the York site. Along with these measurements, representative soil cores of 1m depth were taken and analysed from all the sites, in order to assess the impact of soil properties on the data.

Much of the field data has now been collected for this PhD, with laboratory work with ERT and soil data analysis 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 inform crop management decisions.

This research was supported by RTP scholarship, SAgE, GRS for International travel, and CRC Honey Bee Products (Project 6).

2: Setting of Electrical resistivity tomography (ERT).

3: Soil coring.

Forest loss in Brazil contributing to rising temperatures

Project team: Assoc Prof Sally Thompson (project leader; sally.thompson@uwa.edu.au)[1], Avery Cohn[2], Nishan Bhattarai[3], Jake Campolo[4], Dr Octavia Crompton[5], David Dralle[6], John Duncan[1]

Collaborating organisations: [1]UWA; [2]Tufts University; [3]University of Michigan; [4]Stanford University; [5]UC Berkeley; [6]California State University

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Forest cover loss in the tropics is well known to cause warming at deforested sites, with maximum temperatures being particularly sensitive. Forest loss causes warming by altering local energy balance and surface roughness, with local changes that can propagate across a wide range of spatial scales. Consequently, temperature increases result from not only changes in forest cover at a site, but also by the aggregate effects of non-local forest loss. We explored such non-local warming within Brazil's Amazon and Cerrado biomes, the region with the world's single largest amount of forest loss since 2000.

We developed a predictive model for maximum daily air temperature based on remotely-sensed land surface temperatures (LST), and estimated how maximum daily air temperature responded to forest loss in neighbouring areas within 1- 50 km from the forested site. Two datasets, one consisting of *in-situ* air temperature observations and a second, larger dataset consisting of ATs derived from remotely-sensed observations of land surface temperature, were used to quantify changes in maximum temperature due to forest cover loss at varying length-scales. We considered undisturbed forest locations (1 km^2 in extent), and forest loss trends in annuli (‹halos›), located 1–2 km, 2–4 km, 4–10 km and 10–50 km from these undisturbed sites.

We demonstrated that (i) local temperatures were sensitive to forest loss at neighbouring sites (1-2 km distant); (ii) temperature change following uniform forest losses was influenced by deforestation up to 50 km away; and (iii) that forest loss to date has caused temperature increases in the Cerrado-Amazon region comparable to those caused by greenhouse-gas driven warming. Our research finds significant and substantial non-local warming, suggesting that historical estimates of warming due to forest cover loss under-estimate warming or mis-attribute warming to local change, where non-local changes also influence the pattern of temperature warming. Overall, we also found deforestation in the Amazon has caused temperatures to rise by about 0.5 degrees Celsius, with those temperature increases evenly split between the warming occurring where forest was lost and warming around that area.

Deforestation in Brazil mostly happened because farmers wanted to increase the land area they could farm. However, our research highlights the long-ranging impact on temperatures from deforestation and how farmers will benefit from forest conservation, which will help protect crops and stock from the worst of temperature extremes. The findings also offer relevance to the importance of the conservation and restoration of forests and woodlands in Australia. For example, Queensland has been clearing forests as rapidly as Brazil, mostly for cattle pasture. We know this is a problem for soil quality, water health and biodiversity, and as this research suggests, it is also likely to worsen the effects of climate warming.

This research is supported by the Gordon and Betty Moore Foundation.

4: Cleared agriculture next to tropical forest in the Amazon. Credit: Kate Evans (Centre for International Forestry Research).

Regulation of greenhouse gas emissions and climate change

Project team: Prof Alex Gardner[1] (project leader; alex.gardner@uwa.edu.au)

Collaborating organisations: [1]UWA

Western Australia's increasing greenhouse gas emissions and the climate change impacts are an enormous threat to the agricultural industry in this state. Climate change is already causing harm to many Western Australians and presents the acknowledged risk of much greater harm and missed economic opportunities if the WA Government does not act urgently to ensure that we play an equitable part in reducing global greenhouse gas emissions and to assist the community to adapt to the adverse impacts.

In August 2019, The UWA Public Policy Institute and The UWA Centre for Mining, Energy and Natural Resources Law hosted a colloquium titled *"A Carbon Budget for Western Australia"* at UWA's University Club. The colloquium explored the proposal that WA should legislate a carbon budget to reduce the State's greenhouse gas emissions to net zero by 2050. Talks were given by several UWA academics, including Prof Carmen Lawrence on *"The Impacts of Climate Change"*, Dr Marit Kragt on *"Impacts on and responses from the agricultural sector"*, Assoc Prof David Hodgkinson on *"The Paris Agreement"*, Prof Alex Gardner on *"Regulating GHGe under the EP Act (WA)"*, Prof Yanrui Wu on *"Australian LNG Exports to China: Implications for GHGe"*, and Prof Phil Vercoe on *"Options for the livestock industry to become carbon neutral"*.

Following the colloquium, Prof Gardner made a submission to a consultation conducted by the Environmental Protection Authority, regarding *Guidance on Environmental Impact Assessment of Greenhouse Gas Emissions*. The submission:

1. addresses the EPA's and Government's authority to regulate GHGe under the Environmental Protection Act 1986 (WA) (EP Act), especially in the application of the EPA's mitigation hierarchy that may require a proponent to demonstrate how it will avoid, reduce over time, and offset emissions over the life of the proposal;
2. includes some information on the capacity to take into account measures to assess and mitigate scope 3 (or 'overseas') GHGe from burning fossil fuel exported from WA, with a case study of Chinese law on GHGe mitigation; and
3. comments on the effect of the WA Government's "Greenhouse Gas Emissions Policy for Major Projects", announced in the WA Parliament on 28 August 2019.

In November 2019, Prof Gardner Chaired the *Climate Change Symposium 2019*, held at UWA's University Club. The purpose of the *Climate Change Symposium 2019* was to inform better discussion of and submissions to the State's Climate Policy process, particularly in regard to a *Climate Change in Western Australia Issues Paper* (available at consult.dwer.wa.gov.au/climatechange/issues-paper), published by the Department of Water and Environmental Regulation in early September 2019. The *Climate Change Symposium* included talks from more than 25 academics working in research related to climate change and agriculture, water security, biodiversity, community health, housing, transport, economics, policy, and law. The full program for the symposium can be found at ccs19.com.au/program

Following the *Climate Change Symposium 2019*, Prof Gardner made a submission to the WA Governments' Climate Change Policy consultation. The submission concluded with a recommendation to "develop secure legal arrangements for landscape scale bio-sequestration of carbon dioxide as offsets" for WA emissions.

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What are the barriers to regulating the Wicked Problem of diffuse source pollution from agriculture? An interdisciplinary analysis

Project team: Professor Alex Gardner[1] (project leader; alex.gardner@uwa.edu.au), Professor Carolyn Oldham, Professor Helle Tegner Anker, Ms Jeanette Jensen

Collaborating organisations: [1]UWA (UWA Law School, UWA School of Engineering); [2]Section for Consumption, Bioethics and Governance, University of Copenhagen

Diffuse source pollution from agriculture is considered today's leading water quality problem, both locally and globally, threatening ecosystems, water supply, and public health. The most well-known manifestation of this problem in Australia is in the Great Barrier Reef. In Western Australia, the most prominent examples are the Swan-Canning river system and the Peel-Harvey Estuary.

Agricultural diffuse source pollution is a so-called 'wicked' problem because it is naturally, socially and politically complex. It is naturally complex, as the polluting nutrients (including nitrogen and phosphorus from fertilisers or grazing livestock, fine sediment and pesticides) from agricultural practices enter waters through surface runoff and soil percolation, making their sources difficult to identify and quantify. This raises regulatory challenges because the traditional pollution abatement mechanisms of liability and enforcement are unfeasible. It is socially complex because resolution requires behaviour change on the part of farmers, among others, and would have, or at least be seen to have, an adverse impact on their financial performance. The societal importance of agriculture, both in terms of sustenance and economy, makes the problem politically contentious to address.

This research project aims to identify and define the natural, social and political barriers to regulating agricultural diffuse source pollution in Australia, using Queensland and Western Australia as case studies. Identifying and defining the problem is the first step towards resolution.

In 2019, I analysed the empirical data from a survey and two focus group interviews that I conducted in 2018 with the four main stakeholder groups of government departments, local governments, natural resource management bodies and catchment councils, and industry organisations from both Queensland and Western Australia.

The tree main barriers that emerged to resolving diffuse source pollution from agriculture were short-term funding and programs to address the problem, scientific knowledge gaps, especially site-specific knowledge, and, from the industry's perspective, that farmers bear the cost of reducing the problem.

This research contributes towards resolving the 'wicked' problem of diffuse source pollution from agriculture in Australia by exposing the barriers to resolution, and not just from a regulatory perspective, which is a prerequisite to overcoming them. More broadly, it provides an example of how interdisciplinary research may be conducted to address wicked problems.

This research is supported by RTP, UWA Top-Up Scholarship, and UWA Convocation Postgraduate Research Travel Award.

5: This stream is an example of good water quality.

6: These animals are, unfortunately, part of the problem; their access to water resources should be considered judiciously and, possibly, restricted.

International Water Course

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

Collaborating organisations: [1]UWA

In December 2019, nine Masters of Integrated Water Management students from Griffith University's International Water Centre (IWC) visited UWA for the 8th annual intensive course in *Water, Agricultural Landscapes and Food Security*, coordinated by Professors Susana Neto and Jeff Camkin.

Professor Graeme Martin (UWA Future Farm 2050 Project Manager) hosted the students from Chile, Peru, Nepal, Bangladesh, USA and Australia, as well as the IWC Program Director, Dr Brian McIntosh, for a day at UWA Farm Ridgefield. The students learnt about the new 5500 cubic metre dam, the success of tree plantings around the catchment, and the International Critical Zone Observatory and Flux Tower projects on UWA Farm Ridgefield.

During the visit, the problems of farming with unpredictable rainfall, and the innate ability of Australia's native plants to thrive with minimal water, were discussed. The students were able to see first-hand the challenges facing a typical dryland, mixed-farming enterprise in the WA Wheatbelt.

The students also completed a module on *Water and Agricultural Landscapes* (WATR7800) at UWA and participated in a range of workshops and highly interactive lectures delivered by Professors Kadambot Siddique, Graeme Martin and Edward Barrett-Lennard. In addition, they spent a day in the Swan Valley with Department of Water and Environmental Regulation staff examining the interactions between agriculture and urban planning.

For further information on the Master of Integrated Water Management, please visit watercentre.org/courses/master-of-integrated-water-management/

7: International Water Course participants visited UWA Farm Ridgefield.

UWA represented at Malaysia-UNESCO Cooperation Programme

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

Collaborating organisations: [1]UWA

In November 2019, Adjunct Professors Jeff Camkin and Susana Neto were invited to UNESCO Headquarters in Paris, to participate in the Malaysia-UNESCO Cooperation Programme (MUCP) titled *Roundtable Discussion on Innovative Models for Promoting South-South Cooperation through Education, Sciences, Culture and Communication and Information.*

The Roundtable Discussion was a side-event to the 40th Session of UNESCO's General Conference and aimed to bring together well-renowned actors supporting the SDGs and promotion of South-South Cooperation from Asia, the Pacific and Africa.

Professor Camkin chaired the MUCP Roundtable Discussion and has been supporting UNESCO to synthesise the lessons learnt from the 29 MUCP research projects.

"Since its inception a decade ago, MUCP has engaged nearly 8,000 individuals from 80 countries and established cooperation with at least 160 institutions worldwide," Professor Camkin said. "It is an outstanding example of the benefits of South-South Cooperation."

For further information on MUCP, please visit mucp-mfit.org

8: Adjunct Professors Jeff Camkin and Susana Neto at the UNESCO Headquarters in Paris.

4

Food Quality and Human Health

Theme leaders

Professor Trevor Mori
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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.

1

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3

ARC Discovery project food security and the governance of local knowledge in India and Indonesia

Project team: Hackett Professor Kadambot Siddique[1], Professor Michael Blakeney[1] (project contact: michael.blakeney@uwa.edu.au), Professor Christoph Antons[5], Professor Philippe Cullet[4], Professor Yunita Triwardani Winarto[3], Dr Gregory Acciaioli[1], Dr Jagjit Plahe[1], Professor Jayasree Krishnamurti[2]

Collaborating organisations: [1]UWA; [2]Kerala Agricultural University; [3]University of Indonesia; [4]School of African and Oriental Studies, University of London; [5]University of Newcastle; [6]Monash University

This interdisciplinary project aims to: (1) examine the ways small farmers identify, conserve and exchange useful plant material and incorporate it into cultivated crops through plant selection and breeding under conditions of climate change; (2) identify the ways regulatory structures in India and Indonesia help or hinder this process; and (3) identify opportunities for the application of such local knowledge and its regulatory framework in Australia.

Field trips were undertaken to research sites in Kerala, and to Java and Kalimantan.

This project will result in proposed changes to intellectual property law and other laws to encourage agricultural innovation and enhance farmers' welfare in the face of increased climate variability in India and Indonesia.

Lessons from these countries will help Australian farmers, the government and businesses to develop supportive policies and identify new plant varieties for challenging conditions. A better understanding of local conditions will benefit regulators, NGOs, businesses and aid agencies. The project will also build collaborative international networks of researchers.

Professors Blakeney and Siddique have edited a book of findings from the project: *Local Knowledge, Intellectual Property and Agricultural Innovation*, which will be published by Springer in July 2020.

This research is supported by Australia Research Council.

1: Professors Blakeney and Siddique examining traditional rice varieties in Kerala.

2: Workshop to present the interim results of the project.

Effects of lupin-containing foods on blood sugar levels and blood pressure in type 2 diabetes

Project team: Dr Natalie Ward[3] (project leader; natalie.ward@curtin.edu.au), Professor Jonathan Hodgson[2], Professor Trevor Mori[1], A/Professor Stuart Johnson[3], Dr Caroline Williams[4], Professpr Lawrence Beilin[1], Dr Seng Khee Gan[1], Professor Ian Puddey[1], Professor Richard Woodman[5], Dr Michael Phillips[1], Ms Emma Connolly[2]

Collaborating organisations: [1]UWA (Medical School and IOA), [2]Edith Cowan University, [3]Curtin University; [4]Centre for Entrepreneurial Research and Innovation; [5]Flinders University; Royal Perth Hospital Research Foundation; Sanitarium Health and Wellbeing Company; Il Granino Bakery; Otaway Pasta Company

Type 2 diabetes mellitus is a metabolic disorder characterized by high glucose (blood sugar) and insulin resistance. It is strongly linked to lifestyle factors such as poor diet and physical inactivity. Type 2 diabetes may affect as many as 3.5 million Australians. Early management of type 2 diabetes through diet and lifestyle change can help to maintain blood glucose levels within the normal range, as well as beneficially impacting other cardiovascular disease risk factors such as high blood pressure. Cardiovascular disease is the primary cause of death in people with type 2 diabetes, and type 2 diabetes and hypertension often co-exist, increasing risk of cardiovascular disease and possibly contributing to cognitive impairment.

Lupin is a novel food ingredient which is rich in protein and fibre, with negligible sugar and starch (glycaemic carbohydrate). It can be incorporated into various foods to reduce glycaemic load. Regular consumption of lupin-enriched foods may be a novel and easily achievable means of reducing overall glycaemic load and improving glycaemic control in diabetes.

This project was directed at the earlier stages of diabetes, that is, moderate to well-controlled diabetic participants, where better blood glucose management could slow progression and reduce the need for additional medication or medical intervention. The hypothesis was that regular consumption of lupin-containing food products improves short-term glycaemic control, lowers blood pressure and improves cognitive function in type 2 diabetic participants. The primary aim of the study was to determine whether regular consumption of lupin-enriched foods can improve glycaemic control and lower blood pressure in people with type 2 diabetes mellitus.

Fourteen men and 8 women (mean age 58.0 ± 6.6 years and BMI 29.0 ± 3.5 kg m−2) with type 2 diabetes mellitus were recruited from the general population to take part in a double-blind, randomised, controlled cross-over study. Participants consumed lupin or control foods for breakfast and lunch every day, and for dinner at least 3 days per week, during the 8-week treatment periods. Lupin-enriched foods consisted of bread, pasta, Weetbix™ cereal and crumbs, with energy-matched control products. Treatments were completed in random order with an 8-week washout period. All participants monitored their blood glucose levels pre- and post-breakfast and lunch, and their blood pressure in the morning and evening, 3 days per week for the duration of each treatment period.

Seventeen participants completed both treatment arms, with all 22 participants (14 males, 8 females) analysed. Eight weeks consumption of lupin-enriched food had no significant effect on mean blood glucose levels (mean difference: −0.08 ± 0.06 mmol/L) or post-meal blood glucose levels (−0.13 ± 0.10 mmol/L). That is, the observed difference between lupin and control was small and not significant. There was also no effect on blood pressure or on body weight.

Therefore, despite data from non-diabetic individuals indicating possible benefits on glycaemic control, insulin sensitivity and blood pressure, this study found that regular consumption of lupin-enriched foods had no significant effect on glycaemic control or blood pressure in people with type 2 diabetes mellitus.

This research was supported by Royal Perth Hospital Medical Research Foundation and Sanitarium Health and Wellbeing Company.

3: Lupin foods.


Early growth of chickpea plants from seeds with low seed phosphorus could be enhanced by phosphorus supply

Project team: Professor Hans Lambers[1] (project leader; hans.lambers@uwa.edu.au), Dr Xiao Wang[1,2], Dr Jiayin Pang[1], Hackett Professor Kadambot Siddique[1], Mr Gautier Gadot[3], Mr Axel De Borda[4]

Collaborating organisations: [1]UWA; [2]Shandong University; [3]Institut Polytechnique UniLaSalle; [4]Ecole d'Ingénieurs de PURPAN

Seeds of cereals and legumes, including chickpea, contain vast amounts of phosphorus (P), mostly as phytate, which requires vast inputs of P fertiliser. As phytate cannot be metabolised by humans and other monogastric animals, it is undesirable from a human and animal nutrition perspective. Moreover, phytate tightly binds micronutrients such as zinc (Zn) and iron (Fe). Therefore, seeds with low P concentration and big seed size are a desirable breeding target.

However, seeds need sufficient P to allow germination and vigorous early growth. To test whether a low seed P content affects early growth of chickpea, and whether a P supply during germination can compensate any slow growth of plant with a low seed P content, we selected 23 chickpea genotypes with contrasting seed size and P concentration. We divided seedlings of these genotypes into four groups: one group received P during germination, a control group received no P, a group that had one cotyledon removed, and a fourth group that had both cotyledons removed. Both P supply and a high seed P content significantly increased shoot and root dry weight and shoot P concentration. Shoot dry weight, root dry weight and leaf area was positively related to seed P content, while specific root length was negatively related to seed P content.

We conclude that a low seed P content was associated with less vigorous early growth of chickpea, but a P supply at germination compensated the growth of genotypes with a low seed P content. Therefore, seeds with a low seed phytate concentration can be bred for and used for crop production, provided P is made available during germination. This strategy will increase the nutritional value of the chickpea seeds and decrease the demand for P in crop production, thus tightening the P cycle in agriculture.

This research was supported by UWA.

4: Example of chickpea genotypes with high seed P content under four different P treatments.

5: Example of chickpea genotypes with low seed P content under four different P treatments.

Redox regulation of dormancy in perennial plant, *Vitis vinifera* cv. Cabernet Souvignon

Project team: Juwita Dewi[1], Emeritus Professor John Considine[1], Dr Santiago Signorelli[1], Professor Christine Foyer[2], Dr Michael Considine[1,3] (project leader; michael.considine@uwa.edu.au)

Collaborating organisations: [1]UWA, [2]The University of Birmingham, [3]DPIRD

Perennial plants, such as *Vitis vinifera,* experience dormancy to adapt to environmental changes. The regulation of dormancy has been widely studied and the results showed that the complexity of dormancy phenomenon is governed by endogenous and exogenous signals such as plant hormones, light intensity, and temperature. However, little is known regarding the role of reactive oxygen species (ROS) and reduction-oxidation (redox) metabolism in regulating dormancy, especially in perennial plants. ROS conventionally only associated with plants stresses and oxidative damage. This understanding has recently shifted as evidence show that ROS and redox play essential roles in controlling plants growth and development include dormancy. Therefore, this project is aimed to investigate the involvement of redox in governing bud dormancy in grapevine (*Vitis vinifera*) cv. Cabernet Sauvignon, integrate this with the regulation of plants hormone Abscisic acid (ABA), and to determine whether the response to oxidative changes is influenced by the developmental stage of the buds.

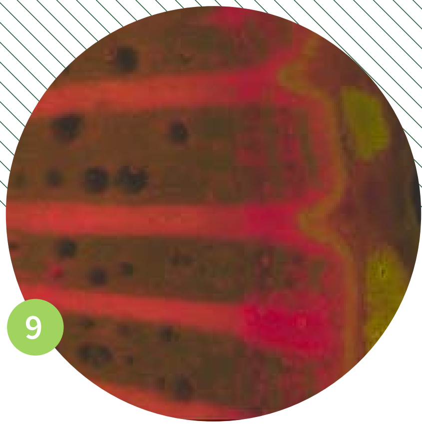
A series of experiments have been done with grapevine single-node cutting of three different developmental stages, by exposing them to ascorbate, dithiothreitol (DTT), hydrogen peroxide (H_2O_2), abscisic acid (ABA), and ABA inhibitor (AA1), alone or in combination. The dynamic of bud burst and cell cycle of the mitotic index has shown that exposure to those chemicals significantly alters the response of dormancy release relative to the control. Moreover, the response was developmentally depended. A further ascorbate and glutathione analysis are in progress to support the previous evidence. Ascorbate and glutathione are the most abundant low molecular antioxidants in plants. These compounds are the main actors responsible for maintaining redox homeostatic in the plant cell, which influence signalling cascade related to plant growth, development, and stress responses.

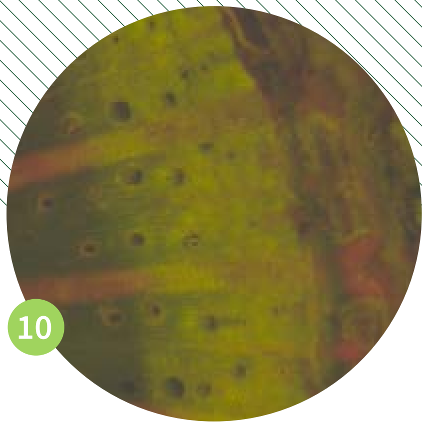
Axillary bud development is critical as it defines the production of fruits in the upcoming season. The asynchronous growth of the axillary buds in grapevine could cause production loss, and it has been a significant issue in warm winter region like Western Australia. This study might provide an insight for better farming practice to reduce production loss.

This research was supported by the Australian Research Council (DP150103211) and Australia Awards scholarship.

6: Part of bud burst experiments, where single node cuttings were treated with AA1, ASC+AA1, ABA, H_2O_2, and hydrogen cynamide.

7: Samples collection at Mosswood vineyard in Margaret River, Western Australia.





Understanding the vascular super highway in perennial grapevine stems

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

Collaborating organisations: [1]UWA (CMCA and IOA), [2]DPIRD

The movement of carbohydrates in perennial plant systems is complex. Previous storage of, current production of, and demand for carbohydrates all influence the movement of sugar to ripening fruit. The vascular anatomy of this system is not well understood.

Longitudinal sugar transport has long been thought to occur via grapevine stem phloem. Recent research from Dr Wisdom's thesis regarding manipulation of carbohydrate source in the later parts of ripening, suggests that this might not be the sole mechanism.

This research aims to examine the histology of retranslocation of carbohydrates from the vine corpus to the fruit in the late part of ripening. This was achieved by application of a fluorescent tracer dye to the stem to make visual the effect of removing the influence of current carbohydrates, through complete shoot removal and manipulation of phloem presence.

Preliminary results suggest that retranslocation of carbohydrates in the grapevine stem may not be confined to the phloem. A perfusion of dye was observed in the xylem rays, in the xylem fibres and surrounding xylem vessels. The presence of this fluorescent tracer dye (fluorescein diacetate) suggests that there is a symplastic pathway from phloem to xylem around disruption to phloem connectivity. The dye was also observed in the xylem below the disruption point, suggesting that the xylem may be involved in long distance sugar transport regardless of wounding.

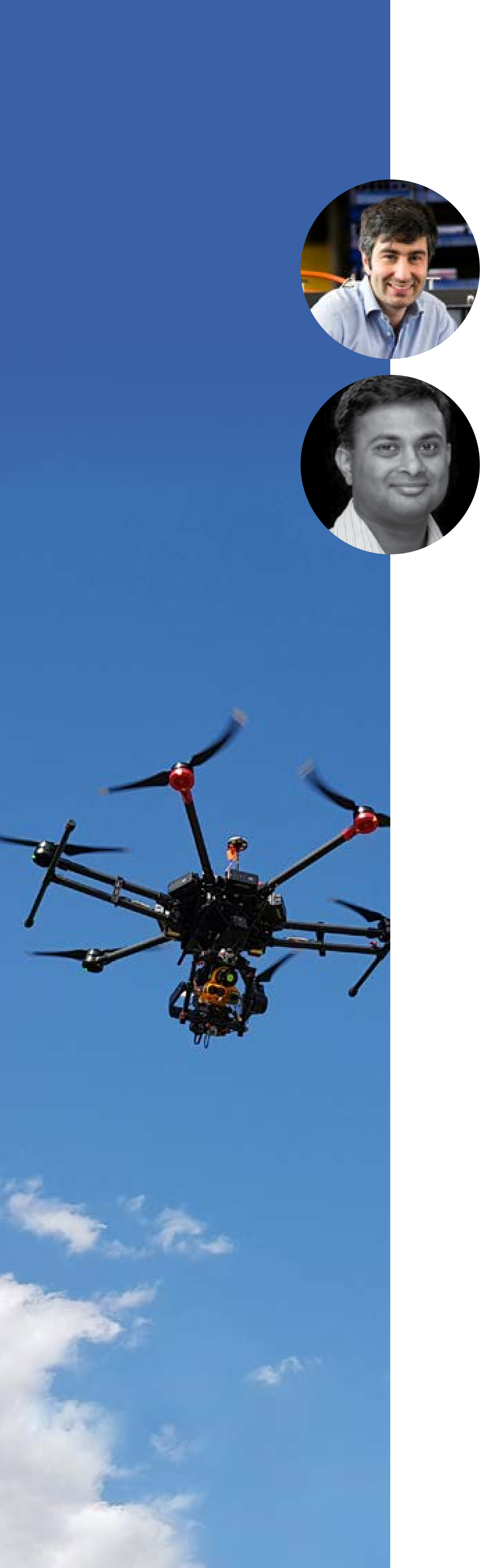
This is preliminary work in the context of understanding vascular function in perennial plants and its influence on how they respond to the environment and season in which they are grown. In wine and table grapes, understanding the pathways for sugar movement through the important ripening period is crucial for manipulating the partitioning of carbohydrates, canopy management and particularly fruit quality. Improving our understanding of the vascular system and response to environment and season allows us to exploit new growing regions within the state and potential challenges faced with a changing climate. Progressing our understanding of the dynamic physiology of perennial tree crops has implications for understanding carbon allocation and water relations in trees in general.

This research was supported by IOA and DPIRD.

8: Cabernet Sauvignon in Mount Barker at véraison.

9: Fluorescent light micrograph of a cross section taken through grapevine stem (control).

10: Fluorescent light micrograph of a cross section taken through grapevine stem (treatment).



5

Engineering Innovations for Food Production

Theme leaders

Dr Andrew Guzzomi
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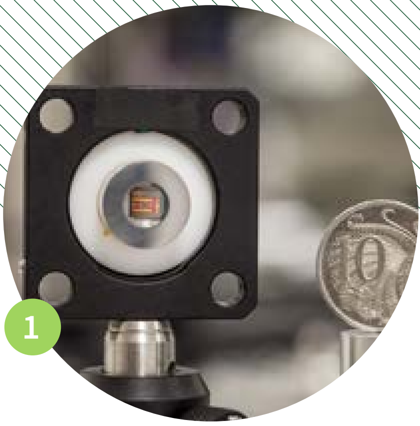
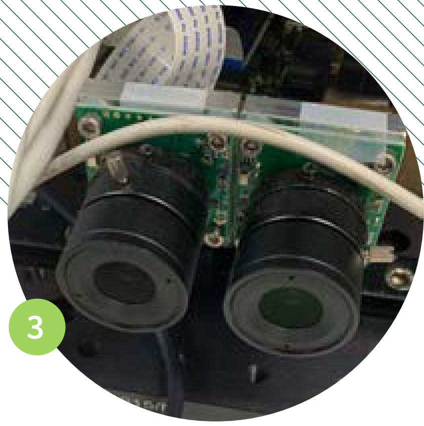
The engineering innovations for food production theme focuses on providing engineering solutions to agriculture for sustainable growth of net farm yield, reduction of wastage, and minimisation of environmental impact. As we head towards 2050 and face the need to feed 50% more people on fewer resources, 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 (R&D) focused on bringing about commercial innovation.





Portable multispectral/ hyperspectral sensors for crop management

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

Collaborating organisations: UWA

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

This research is an on-going project, supported over the years by multiple organizations, including GRDC, multiple defence organizations (US and Australian), and the Australian Research Council.

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

2: The portable sensors are now being assembled on drone platforms for on-farm applications.

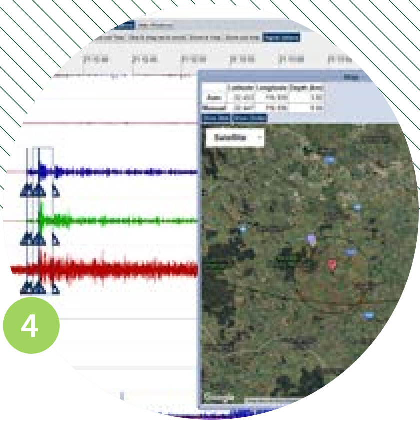
Multispectral imaging for characterisation of crop and animal products

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

Collaborating organisations: UWA, US Dept. of Agriculture

Low-cost multispectral cameras have the potential to revolutionize in characterisation of crop and animal products, as well as in the contamination testing in both. A new partnership between IOA researchers in the faculty of engineering, with collaborators at the US Department of Agriculture (USDA) in Athens, GA., aims to add multispectral capability into existing low-cost cameras to serve industry needs. This project was initiated as a result of a visit by 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 Kim Chance Fellowship scheme.

3: Low cost multispectral camera.



UWA Farm Ridgefield seismograph

Project team: Vic Dent (project leader; vic_dent@yahoo.com)

Collaborating organisations: UWA

The seismograph at Ridgefield farm continued to operate through 2019, except for a one month data gap from 9th October to 6th November, at which time the equipment was moved from the old house to a transportable near the shearing shed. It is expected that the gear will experience less disturbance at this new location. The equipment detected approx. 100 earthquakes in the wheatbelt region in 2019, including a group of four small events about 30 km east of the farm, a magnitude 3.1 event north of Brookton (19th March), and a magnitude 1.9 event about 9 km northwest of the farm (8th July, pictured). The largest wheatbelt earthquake it recorded was a magnitude 4.3 event near Newdegate on 20th June, 2019.

4: A magnitude 1.9 event about 9 km northwest of the farm occurred on 8th July 2019.

Weed Chipper progresses to commercialisation

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

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

Commercial Partner: Precision Agronomics Australia

The targeted tillage “Weed Chipper” (Figure 1) 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 A/Professor 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 local Western Australia company Precision Agronomics Australia and it is expected that units will be available to farmers in late 2020.

The research that led to the development of the Weed Chipper was supported by GRDC.

5: Dr Andrew Guzzomi with the award winning Weed Chipper. Photo: Anvil Media.

6: Dr Andrew Guzzomi and Associate Professor Michael Walsh presented with the Rio Tinto Emerging Category WA Innovator of the Year Award.

Profitable and environmentally sustainable subclover and medic seed harvesting

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

Collaborating organisations: UWA

This project commenced in late 2018 and comprises a multi-disciplinary research team with skills in agricultural engineering, pasture agronomy, and breeding and plant 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 focuses on subterranean clover, but principles will also apply to annual medics.

Wesley Moss commenced his PhD studies in January 2019 as part of the project. A series of workshops were held in WA, SA and NSW to capture the ideas and experiences of local seed growers and agronomists. These workshops, together with case studies of leading seed producers, informed the design of an industry-wide survey to collate information on current seed harvesting practices and technology. Previous harvest machinery was also investigated, which revealed an impressive history of Australian innovation of design and modifications. Often these have been undertaken in isolation within a farm or district and have not previously been documented or shared.

The research team also acquired a limited edition red Horwood Bagshaw vacuum seed harvester, kindly loaned to UWA by Rodney and Jane Rogers from Cunderdin, WA. This is being used to benchmark the performance of current harvesting technology, test out a range of modifications and provide comparisons with other harvest machinery.

This research is supported by AgriFutures Australia. PhD candidate Wesley Moss is the recipient of a Robert and Maude Gledden Postgraduate Scholarship and an AW Howard Memorial Trust Research Fellowship.

7: Project team with the red Horwood Bagshaw at UWA. Standing (left to right): Assoc. Professor Megan Ryan, Professor Willie Erskine, Dr Kevin Foster and Assoc. Professor Phil Nichols; kneeling (left to right) Dr Andrew Guzzomi and PhD student Wesley Moss.

8: Harvesting subterranean clover seeds in Naracoorte, South Australia.

6

Agribusiness Ecosystems

Theme Leaders

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Marketing (UWA Business School)
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The agribusiness ecosystem theme is about the interconnectedness and linkages of agricultural enterprises with each other and also 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, representing 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, and receiving services from government and educational institutions.

The aim of the Agribusiness Ecosystem theme at the UWA Institute of Agriculture is to advance scholarship on socio and economic issues affecting agriculture locally in Western Australia, at the national level in Australia, also 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 Ecosystem theme in 2019. Our research focus contributes to the realisation of the 2030 Agenda of Sustainable Development.

1

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), 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 organizations: [1]UWA; [2]University of Bristol; [3]University of Nairobi; [4]University of Ghana; [5]LUANAR

The aim of this project was 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 UN SDGs and 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.

Two workshops and fieldwork were held in Lilongwe, Malawi, and Accra, Ghana, to collect data from smallholder dairy cooperatives/associations and dairy farmers. Under the leadership of Prof Liveness Banda, the fieldwork in Malawi was conducted from 11-17 September, to collect data from 2 dairy cooperatives and 30 dairy farmers affiliated to the cooperatives. This was followed by a two day workshop held at LUANAR on 19-20 September. In Ghana, Prof Frederick Obese directed the fieldwork from 15-18 November, to collect data from 3 dairy farmers associations and 30 dairy farmers affiliated to the associations. A two day workshop was held on 2-3 December, at the University of Ghana, to review the fieldwork results and compare the data obtained from Ghana and Malawi.

The project was successful in linking and facilitating three Early Career Researchers from Malawi, Ghana, and Kenya, to jointly conduct fieldwork in the respective countries, analyze the data under the guidance of the Principal Investigators and prepare field reports and oral presentations to achieve the project's objectives. When this project is complete and successful, it will provide baseline information that can be used to develop data collection protocols to monitor and evaluate best management practices in smallholder dairy cooperatives.

This project is supported by grants from the Australia Africa University Networks and the Worldwide University Networks.

Forecasting Commodity Price Volatility in Agricultural Markets using Artificial Intelligence Models with Forecast Combination Strategy

Project Team: Dr Amin Mugera[1], Liwen Ling[2] (project leader; linglw@scau.edu.cn), Dabin Zhang[2]

Collaborating Organizations: [1]UWA; [2]South China Agricultural University

Forecasting the future price of agricultural commodities is one of the most essential decisions making activities for all participants in the agricultural sector, including producers, traders, hedgers and speculators, as well as policymakers. Commodity price volatility has intensified in the past decades, making it a challenging task to forecast by simple models. Artificial intelligence (AI) model with excellent self-adaptive and self-learning capacities have recently become an effective tool for complex time series forecast modeling. These state-of-the-art techniques should be introduced and tested in agricultural markets to further improve forecast accuracy. Another feasible approach to improve the forecast performance is the strategy of forecast combination. The diversities of forecast combination help to reduce the uncertainty in modeling, thus providing a better prediction. Besides the most commonly used technique of combining different kinds of models, e.g., statistical models and AI models, combining the variables from different sources and different time scales is an emerging approach for forecast combination. This project aimed to fill the research gap by using AI models as well as novel forecast combination strategies to further improve price forecast performance in the agricultural market.

Owing to the promising performance in both academic research and business application, two popular and powerful AI models, support vector regression (SVR) and extreme learning machine (ELM) were specified as the forecast modeling techniques in this project. We conducted three experiments: (i) a forecast combination framework based on different time scales for livestock products' price prediction. It is believed that different time scales (e.g., weekly and monthly forecasts) capture different price dynamics (i.e., short- and long-term price movements); (ii) considering animal disease is a vital external shock to pork price volatility; thus, online search data is crawled from the internet to reflect people's concern about the disease, an animal disease composite index (ADCI) is formulated and used as an additional input of the forecasting model; and (iii) a novel hybrid modelling framework, which considers the cointegration of the upper and lower boundaries of price series, is constructed for the interval-valued pork price forecasting, and a reasonable data transformation process is designed to compare the performance between interval and point forecasting.

Using the livestock products' price in China as a research sample, the empirical results demonstrate that:

1. The short-term forecast accuracy can be remarkably improved by combing the long-term forecast. Among various combination methods, the variance-based weighting scheme yields a superior result compared to the best single forecast.
2. The outbreak of animal disease is found to have a long-term effect (nearly one year) on price volatility. By coupling the online search data with the original forecast model, which only contains the historical observations, both the level and directional forecast accuracy can be dramatically enhanced in multi-steps forecast horizons. Moreover, considering the impacts of substitute products can further improve the forecast performance.
3. Coin-AIs which involve the cointegration of upper and lower bounds generate a promising performance improvement ratio compared with the single AI models. With the data transformation process, interval forecast is shown to be more accurate than point forecast, especially in mid- and long-term forecast horizons.
4. Regarding the performance of AI models, SVR and ELM outperform the traditional statistical model, i.e., naïve model, autoregressive integrated moving average model, and exponential smoothing model. In general, the superiorities of AI models and the effectiveness of forecast combination strategy with different time scales and data sources have been verified in the agricultural market.

This project is supported by the National Natural Science Foundation of China (Grant number: 71971089).

1: Liwen Ling, South China Agricultural University.

Agricultural innovations for communities (AI-Com) in East Timor

Project team: Professor William Erskine[1] (project leader; william.erskine@uwa.edu.au), Hackett Professor Kadambot Siddique[1], Professor Anu Rammohan[1], Dr Pyone Thu[1], Rob Williams[1], Dr Amin Mugera[1]

Collaborating organizations: [1]UWA; MAF; UNTL; World Vision

The project aims to improve agricultural productivity and profitability in pilot communities in East Timor, by addressing technical and social impediments to annual crop intensification and establishing fodder tree legumes and sandalwood to sustain both income and land. The project is being implemented by a program management group including MAF, UNTL, World Vision, and UWA, with inputs from major development and private industry partners. It builds on the successful collaborative project management approach used by Seeds of Life.

In 2019, a team comprising of socio-economists from AI-Com and MAF, and UNTL students, undertook an evaluation of the impact of participatory land-use planning (PLUP). This included prohibition through traditional community decision making (*tara bandu*) of specific land management practices, on conservation agriculture (CA) and velvet bean adoption on the south coast. The survey used both quantitative and qualitative methods and covered 374 respondents. The results showed that conservation agriculture with velvet bean increased the maize production of adopting farmers. Conservation agriculture with velvet bean was primarily adopted for weed suppression and soil fertility in addition to increased maize production. Grazing management was widely understood to be a key issue in conservation agriculture adoption. PLUP did not improve the outcome of conservation agriculture.

In 2019, following up trials in 2018 which showed the dramatic effects of fertilizers (e.g. N, P & rice-hull biochar) on the yields of a range of crops following rice in a nutrient-impoverished soil, fertilizer trials were undertaken on rice by UNTL and MAF in a wide range of sites. Large responses to the application of N and P fertilizer and rice-hull biochar were found. In 2019, MAF explored biochar use specifically on high-value vegetable crops at three sites. Common fertilizer treatments used were 1. Control, 2. Local fertilizer (cow manure at 1200 kg/ha), 3. Rice-hull biochar (30 t/ha), 4. Superphosphate (SP-36) at 80 kg/ha, and 5. Biochar + SP-36. The specific crops varied across sites depending on local usage. At all sites and with most crops, the combination of SP-36 and biochar gave the best yield. An economic analysis on the previous year's agronomic data showed that for high-value horticultural crops, such as tomato and chilli pepper, biochar application was very beneficial, but not so for field crops, such as maize and mung beans. For hosting farmers this was the first time to see superphosphate and biochar in use on these crops. Further research is underway on the use of fertilizer (SP-36 and biochar) on high-value crops.

In research to evaluate methods for communities to increase forage supply from forage tree legumes (FTL) and sandalwood production, we initiated planting sandalwood with the FTL - *Leucaena* in ten communities to understand the impact of micro-dosing NPK and cow manure on sandalwood establishment. One year following planting, the tree survival rate varied markedly across farmers and sites from 100 % survival with two farmers down to 20 % at the poorest site. Good host and sandalwood management are crucial to survival and early growth.

Seedling establishment is often problematic in sandalwood due to poor germination. MAF tested the impact of GA_3 on the germination of sandalwood seeds. GA_3 use reduced the speed of germination and increased total germination from 25 % to maximum sandalwood germination of 67-78 %. This can dramatically improve nursery output.

Training was an important AI-Com activity focusing on MAF research staff and UNTL students, with a total of 245 days of training given, of which 27% were with women. Additionally, cooperation with UNTL has linked project agronomic implementation to student capacity building. Fourth-year student research projects have involved a total of 45 students (11F/34M) to date.

This project is supported by an ACIAR grant.

Determinants and Impacts of Sustainable Intensification Practices among Smallholder Maize Producers in Tanzania

Project team: Dr Amin Mugera[1] (project leader; amin.mugera@uwa.edu.au), Mr Makelemo M. Mkanday[1]

Collaborating organizations: [1]UWA

This project analysed rural household survey data from Tanzania to investigate smallholder farmers' decision to adopt multiple sustainable agricultural intensification (SAI) practices (contour farming, improved seed varieties, and rotation cropping) and the impact of the adoption of those practices on maize yield while controlling for potential endogeneity and selection bias arising from the choice to participate in the Africa RISING program that promoted the adoption of SAI practices.

We find significant complementary relation between contour ploughing and rotation cropping, suggesting that joint adoption of these practices would increase the expected farm benefits through the spillover effect of one on the other. Better education of farmers, access to information, government extension services and institutional support, and participation in the Africa RISING program positively influence the adoption of improved seed varieties and rotation cropping. Livestock ownership influences the adoption of rotation cropping while the adoption of contour ploughing relates positively to farmers' access to new farm technologies and their experience of soil erosion in their parcels. The results also indicate that the adoption of improved seed varieties and rotation cropping through the Africa RISING program significantly increases maize yields. Our findings imply the scaling-up of Africa RISING program's interventions countrywide and strengthen rural agricultural institutions, farmers' unions or local affiliations, and farm information sources, are important incentives to encourage farmers to adopt SAI practices which consequently improve smallholder farmers' yields.

This research is supported by Australia Award scholarship

Economic analysis of the feasibility of Investing in pivot irrigation for pastures and beef production in the Pilbara region of Western Australia

Project team: Professor Philip Vercoe[1], Ms Renata Togneli[1], Dr Amin Mugera[1] (project leader; amin.mugera@uwa.edu.au), Dr Clinton Revell[2]

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

Beef cattle production based on grazing native pastures is one of the main economic land uses of the rangelands of Western Australia (WA). However, production has continued to be a challenge and long term viability and sustainability of beef enterprises remains uncertain. This is partly due to the low quantity and quality of pastures during the dry season, leading to poor animal productivity and profitability. Developing irrigation systems has been suggested as a feasible strategy to supply pastures with high nutritional value consistently, to improve reproductive rates, animal growth rates, and exploit new markets. However, there is little information on the economic feasibility of irrigation development for beef production in the Pilbara region of WA.

This study adapted and linked two different bio-economic models to simulate the development of pivot irrigation for a case study beef enterprise in the Pilbara region. Two different pastures production strategies (high-quality feed and low-quality feed) were compared and the financial returns on three different beef cattle management scenarios (early weaning, heifer supplementation, and rapid turn-off of steers) were investigated. Our results showed improvements in beef cattle productivity in all the simulated irrigation scenarios. However, the projected returns on investment ranged from negative to moderately positive (IRR from -5% to 40%) across the different scenarios over a 15 year time horizon. The positive returns on investment were obtained in scenarios with high-quality pastures. The most profitable scenario was to perform early weaning of calves and feed them with high-quality forages with the main objective of improving breeder reproductive rates and decreasing mortality rates. The main implications of my study are that investors will need to be prudent when considering irrigation because their investment has a long payback time and is very sensitive to the liveweight sale price of steers, hay yield, and discount rate.

This research was supported by the Argentinian Government scholarship to Renata Togneli

Lifting the productive efficiency of smallholder maize farmers in Ethiopia: A meta-frontier analysis of conventional and minimum tillage

Project team: Dr Amin Mugera[1] (project leader; amin.mugera@uwa.edu.au), Mr Stanley Njoki

Collaborating organizations: [1]UWA

Enhancing agricultural productivity in the face of deteriorating environmental conditions is one way through which a nation can improve its agricultural production and food security. Although a lot of studies have been done on the impacts of conservation agriculture (CA), very little attention has been given on the effects of CA on the technical efficiency of smallholder farmers. Using a meta-frontier analysis, this study investigated the impacts of the adoption of minimum tillage practice (MTP) as a component of conservation agriculture on the productive efficiency of smallholder maize farmers in South Achefer district in North-west Ethiopia. Bias-corrected technical efficiency estimates were estimated for the survey data that comprised of 484 plots (114 plots under minimum tillage practice and 370 plots under conventional tillage) from 245 households from the data that was collected in March 2013. The determinants of technical efficiency were investigated using OLS and the treatment effects were determined using endogenous switching regression. The study found that technical efficiency from minimum tillage practice is much higher than the technical efficiency of conventional tillage both at the group-specific and meta-frontier. Controlling for self-selection and endogeneity yielded an average treatment effect of MTP on technical efficiency of 0.11%. Careful trainee selection and intensified awareness on minimum tillage can go a long way in improving adoption and by extension improve technical efficiency. Non-adopters stand to gain by adopting the practice.

This research is supported by Australia Award scholarship

Does Contract Farming Improve Productive Efficiency? Evidence from Ginger Farming in Nepal

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Collaborating organizations: [1]UWA

The emerging empirical literature on contract farming in developing countries has mainly focused on adoption and its impacts on yield and farm income. A small number of studies have investigated the impact of the adoption of contract farming on technical efficiency while addressing self-selection and unobserved heterogeneity concerns. Using a farm-level data survey of 605 ginger farmers in Nepal, this study investigates whether contract farming improves the productive efficiency of smallholder ginger farmers using the data envelopment analysis (DEA) method. Self-selection into contract farming was addressed; using the propensity score matching (PSM) method and endogenous switching regression (ESR) to account for unobserved heterogeneity in farmers' decision to adopt contract farming. We find that technical efficiency is higher for ginger contract farmers than for conventional farmers. We found a negative association between contract farming participation among ginger contract farmers and technical efficiency.

From the farm data used in this study, our findings revealed that use of bulls in farming and bulls being located a close distance to the market, is associated with a higher increase in the technical efficiency of ginger contract farmers. Female-headed households are more technically efficient compared to their male counterparts. Market access, the use of bulls and the cooperative willingness to buy ginger are found to be the main motive behind contract adoption. We also found that smallholder farmers will achieve higher technical efficiency by adopting contract farming, and that female-headed households tended to have a higher level of technical efficiency compared to their male counterparts. The implication of these results signifies interventions from institutions in the input and output market which will induce the actors in contract farming for effective agribusiness.

This research is supported by Australia Award scholarship

New methods for designing year-round high-value honey production sites and systems

Project team: Dr Michael Renton (project leader; michael.renton@uwa.edu.au), Dr Pieter Poot, Joanne Picknoll, Iris Sietsma

Collaborating organizations: UWA; CRC for Honey Bee Products; Honey for Life; Boathaugh Estate

Resources for apiarists are diminishing and beekeepers must now travel large distances to find plants that are adequate to feed their hives and produce a crop of honey. To tackle this problem, we are beginning to restore sites with bee plants. However, we need an approach to identify the best choice of plants and the best way to arrange the plants on the site. We also need to understand how many hives the plants can support, the best way to arrange the hives on the site and the best time to move the hives (around the site or between sites if necessary).

This project will develop a new approach to help answer these and other questions faced by apiculturists when selecting and establishing new hive sites. This includes creating a model to predict how different plant selections, planting arrangements, and hive management strategies affect honey production. Models will enable apiculturists to synchronize the amount of nectar and pollen supplied at the site with the temporally changing demands of the colony. Early spring flowering pollen producers will be particularly important for building strong colonies before major nectar flows, whilst summer flowering nectar producers will be important to feed the expanded colony and enable foragers to collect surplus nectar for winter stores.

Models will account for the temporal variation in nectar and pollen production of different plant species and the temporal variation in available hours for collecting nectar and pollen (due to seasonal climatic conditions). They will also account for hive population dynamics as well as spatial factors affecting the way foragers access and collect resources.

The first aim of the project, which was to identify the requirements for methods to help design year-round, high-value apicultural operations, is now complete. The next stage will be the completion of the non-spatial model predicting honey production based on surrounding flora. The final stage is to develop a model that includes spatial aspects of foraging and a method for optimizing planting designs and maximizing honey production.

In May and June 2019, researchers Joanne Picknoll and Iris Sietsma investigated different methods for estimating nectar production, including the anthrone method, digital refractometers, and High Performance Liquid Chromatography (HPLC). The researchers also studied the variation in nectar production between flowers (within and between plants). Plants sampled included *Banksia menziesii*, *Eucalyptus erythrocorys* and *E. caesia*.

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

2: Joanne Picknoll (left) and Iris Sietsma (right) measured nectar production in *E. erythrocorys*. Photo: Joanne Picknoll.

An economic analysis of sheep flock structure for broadacre farm businesses

Project team: Michael Young[1,2], Professor Ross Kingwell[1,2], John Young[3], Professor Philip Vercoe[1] (project leader; phil.vercoe@uwa.edu.au)

Collaborating organizations: [1]UWA; [2]Australian Export Grains Innovation Centre; [3]Farming Systems Analysis

A strategic question facing many mixed enterprise broadacre farm businesses in Australia is, 'What sheep flock size and structure are most profitable to complement the farm's cropping enterprises?' This study answers this question for a typical large mixed enterprise farm business in a key production region of Western Australia.

Whole-farm bioeconomic modelling, combined with broad-ranging sensitivity analysis, is used to examine the profitability of different sheep flock structures and sizes. Whole-farm planning allows farmers to identify what areas of the farm system are current and potential drivers of profit, and how they should be managed to maximise whole-farm profit. We have conducted a whole-farm analysis that illustrates how the structure of a farm's sheep flock, its rotations across a range of soils, and overall cropping intensity are all factors that significantly affect profit and need to be considered when determining an optimal farm strategy.

This study assessed the role and profitability of different flock structures in a mixed enterprise farm business in the grain-belt region of Western Australia. We found that farm profit was greater when a Merino flock turning off finished lambs was selected. These flocks remained the most profitable among a range of flock options, even if key input prices and commodity prices were subject to moderate change. However, to achieve the maximum profit, these flocks required more attention to sheep management. The choice of flock structure had a larger impact on profit than moderate changes in land allocation to cropping. Selection of the most profitable flock structure generated double the farm profit from that of the least profitable flock structure. More conservatively, a farm plan based on cropping and a self-replacing Merino flock, using surplus ewes for first-cross, meat lamb production earned 33 % more profit than a farm plan based on a traditional self-replacing Merino flock that emphasized wool production. An additional feature of optimal farm plans was to commit to continuous pasture on all the poor soils, whilst continuously cropping the more productive soils, with some complementary areas of permanent pasture. Allocating 40–60 percent of the farm area to cropping was optimal, although this was affected by relative commodity prices.

This project was funded by Sheep Industry Business Innovation, Sir Eric Smart and Edith Easthope.

3: Michael Young, UWA Agricultural Science student.

Analyse efficiency of smallholder farm's tree and crop production in upland areas of Vietnam

Project team: Associate Professor Atakelty Hailu, Associate Professor Chubo Ma, Le Van Cuong (project leader; vancuong.le@research.uwa.edu.au)

Trees and crops play a crucial part in upland agriculture in Vietnam, where important cash crops producing highly export-oriented products are mostly cultivated. However, low production efficiency is still a major challenge for upland smallholder farming, with considerable productivity gaps between farms even for the same crops. This study will investigate the degree of productive efficiency and its determinants at the whole-farm level for both tree and crop production and examine farmers' preferences about government policies that influence land use. It will generate information that would help bridge the gap between government policies and smallholder farmers' motivation for their current tree and crop choices and their willingness to change such choices for higher efficiency. The research will employ stochastic frontier analysis and distance functions to investigate the efficiency of smallholder farms and a choice experiment to analyse farmers' preferences.

The research activities implemented in 2019 are the literature review on production efficiency and design of the survey in 2020. The main activities for survey design include the design of questionnaires and choice experiments. My research project has not started to collect data. Thus, there have been no publications and conference papers.

This project was supported by UPAIS-University Postgraduate Award and International Fees Offset (RTPFI – RTP).

Child and Household Level Determinants of Child Malnutrition in Punjab, Pakistan: A Cross-sectional Study

Project team: Dr Amin Mugera[1] (project leader; amin.mugera@uwa.edu.au), Professor Michael Burton, Mr Faris Naseeb

Collaborating organizations: [1]UWA

Pakistan is one of the countries with the highest rates of child malnutrition, and its progress in reversing the situation is slower than its neighbours in South Asia. This study used linear and logistic regression models to analyse a sample of 15,760 children younger than 5 years old from Punjab, Pakistan, to investigate child and household level factors associated with child nutritional outcomes. The continuous outcome variables of interests were WHO anthropometric measures based on z-scores (weight-for-height [WHZ], height-for-age [HAZ] and weight-for-age [WAZ]). The binary outcome variables of interest were prevalence of wasting (WHZ<-2), stunting (HAZ<-2), and being underweight (WAZ<-2).

The proportions of malnourished children were high; with around 14% wasted, 37% stunted and 34% were underweight. The study found that maternal education and household wealth were the most significant correlates increasing child WHZ, HAZ, and WAZ (P<0.01) and reducing the likelihood of children being malnourished. Household ownership of agricultural land and household head educational level were also associated with reduced risk of a child being underweight and stunted. Root foods significantly increased HAZ, grain foods significantly increased WHZ and reduced likelihood of wasting, and solid or semi-solid foods significantly increased HAZ and WAZ and reduced likelihood of stunting and being underweight in children below 3 years old. Infant vaccination reduced the likelihood of being underweight. Having a refrigerator reduced the risk of stunting and being underweight. Living in larger households was associated with lower HAZ and WAZ, and reduced prevalence of stunting and being underweight for children aged 3 and 4, who also tended to have lower WHZ, HAZ and WAZ and were more likely to be underweight when they were physically hit. Households who were dependent on surface water such as lakes, dams, rivers, and streams for drinking were more likely to have stunted and underweight children (P<0.01).

Policy implications of this study include promoting education (especially of women), insuring appropriate vaccination of infants, promoting agriculture and making it more inclusive through equitable land distribution, raising awareness about the risk of drinking surface water and water from unprotected springs, and finally, improving overall living-standards by systematically addressing poverty.

This research is supported by Australia Award scholarship.

Essays on the Economics of Soil Quality: Crop Productivity, Adoption and Willingness to Accept for Land Restoration Program in Pakistan's Punjab

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

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

Punjab is considered the breadbasket of Pakistan, as it is the net supplier of multiple food commodities. This province has experienced an increase in food demand due to rapid population explosion and this has put pressure on the cropped area. About one-fourth of all irrigated areas are affected by soil salinization, mainly caused by overexploitation of groundwater. 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. 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. Despite the government's efforts to restore salt-affected areas, the adoption of land restoration practices has remained low due to multiple factors that need to be investigated. There is a need to develop an integrated approach to tackle the source of secondary salinization, as well as to reverse salt-affected soil through designing a land restoration program. Farmers' preferences for the design elements of restoration program will be given high priority so that the government can enhance participation rate.

A survey was conducted in 2019 to provide a quantitative basis to identify and address urgent economic policy priorities about land degradation, especially soil salinization. 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 (District: Hafizabad); (ii) Mixed Zone (District: Jhang); and (iii) Cotton-Wheat Zone (District: Bahawalnagar). Data was collected for households who cultivated agricultural plots during the 2018-19 production seasons. The data focused on agricultural production (including inputs and outputs of four major crops i.e. Wheat, Rice, Sugarcane, and Cotton) at the plot-crop level, agricultural water use, farm, and livestock assets, access to extension services, credit, income diversification, adoption practices in salt-affected villages, decision making in agricultural activities, communication technology used in agricultural activities and distance to main infrastructures. Data was collected using a structured questionnaire using five enumerators in which inputs were received from IFPRI and UWA. In addition, soil and water samples (groundwater) were collected from farmers' eligible plots (646) and were analyzed by the University of Agriculture, Faisalabad. Soil samples were analyzed for ten attributes and water for four attributes.

A multi-stage stratified sampling design was employed to select farm household samples. First, out of four provinces of Pakistan, Punjab was selected particularly for irrigated areas because of their relative importance in bulk production of crops. Second, the study randomly selected three districts from irrigated Punjab, representing three agro-climatic zones of Punjab namely: (i) Rice-Wheat Zone (District: Hafizabad); (ii) Mixed Zone (District: Jhang), and (iii) Cotton-Wheat Zones (District: Bahawalnagar) and from each district, 168 farm households were selected. Within each district, two tehsils were purposively selected based on relatively high levels of salt-affected land, after consultation with DD (Deputy Director) Agriculture Extension in each selected district. From each tehsil, 84 farm households were selected. From each tehsil, two Union Councils (UC's) were selected based on the same criteria which were used to select the tehsils. From each UC, 42 farm households were selected. In each UC, two administrative districts were selected: (i) Salt-affected (ii) relatively good soil. Finally, 21 farm households were randomly selected from each administrative district list to be included in the sample. A total of 504 farm households were selected for the survey. The fieldwork (farm household survey) as described above is inconsistent with what was originally proposed in the research proposal.

This research is funded by the International Food Policy Research Institute and the University of Western Australia.

Multi-objective planning in northern Australia: co-benefits and trade-offs between environmental, economic, and cultural outcomes

Project team: Professor David Pannell[1] (project leader; david.pannell@uwa.edu.au), Dr Milena Kiatkoski Kim[1], Mr Ken Wallace[1], Ms Alaya Cotton-Spencer[1], Professor Robert Pressey[2], Dr Jorge Álvarez-Romero[2], Professor Michael Douglas[1], Dr Rosemary Hill[3], Dr Mark Kennard[4], Dr Vanessa Adams[5]

Collaborating organizations: [1]UWA; [2]James Cook University; [3]CSIRO; [4]Griffith University; [5]University of Tasmania

Given the proposed expansion of developments in northern Australia and the potential tensions among stakeholders, there is a need to develop and trial spatially explicit tools to guide planning and management that support multiple uses of land and water, while maintaining environmental and cultural values. This project will demonstrate how to operationalize participatory, multi-objective catchment planning, by which stakeholders can collaboratively construct and assess the outcomes of alternative development and management scenarios (including identifying co-benefits and trade-offs between objectives). The study takes place in the Fitzroy River Catchment in WA. Major components of this exercise include exchanging views about development, imagining possible futures, and exploring their outcomes. The project duration is between 2016 and 2021.

Project activities included five workshops held with multiple stakeholders, including Aboriginal groups, state and federal government, environmental organizations, and representatives of the pastoral, agriculture, mining, and tourism industries.

Two of those workshops, held in Derby and Broome in 2018, focused on the development of future scenarios. The resulting five scenarios explore the future (the year 2050) development outcomes associated with market demands and environmental governance, among other drivers of future change. Three workshops were held in 2019, in Derby, Fitzroy Crossing, and Broome. In two of those workshops, participants assessed the potential impacts of future scenarios on the wellbeing of key interest groups. Results are currently being analyzed and the final project report will be released in late 2020.

This research is supported by funding from the Australian Government's National Environmental Science Programme (NESP).

Transdisciplinary environmental research

Project team: Professor David Pannell[1] (project leader; david.pannell@uwa.edu.au), Dr Milena Kiatkoski Kim[1], Professor Michael Douglas[1], Dr Samantha Setterfield[1], Professor Rosemary Hill[2], Professor Sue Jackson[3], Dr Jorge Álvarez-Romero[4]

Collaborating organizations: [1]UWA, [2]CSIRO, [3]Griffith University, and [4]James Cook University

Transdisciplinary research is solution-oriented, multidisciplinary, and includes participants from outside academia to increase the uptake of research results by users. A group of NESP-NAERH projects in the Fitzroy catchment (WA) are adopting a transdisciplinary approach by having water resource management as a common theme, integrating their research processes and outputs, and developing strong links with research users. Our project will: use lessons learned from other transdisciplinary projects to enhance the Fitzroy group via formative evaluation, assess the achievement of desired outcomes, contribute to the emerging literature on transdisciplinary and inform future environmental research.

Two project workshops with researchers were held in Perth in 2018 and 2019 to support the project formative evaluation. Activities in 2020 include interviews with research participants in the Fitzroy catchment to assess the impacts of the group of NESP-NAERH projects.

This research is supported by funding from the Australian Government's National Environmental Science Programme (NESP).

Australian Co-operative and Mutual Enterprise Index (ACMEI) study

Project team: Winthrop Professor Tim Mazzarol (project leader; tim.mazzarol@uwa.edu.au), Winthrop Professor Geoff Soutar

Each year, since 2014, CERU has undertaken the foundation research for the Business Council of Co-operatives and Mutuals (BCCM), National Mutual Economy Report. This research is undertaken as part of the Australian Co-operative and Mutual Enterprise Index (ACMEI) study, which focuses on the identification and mapping of all the co-operative and mutual enterprises (CMEs) in Australia.

This study involves working with the BCCM and the sector, to collect data on the number of CMEs, as well as key information about their financial and social status, impact, and strategic challenges. Quantitative data and case study data is collected. A baseline report is generated by CERU and used by the BCCM to form the content of their annual report that is used to promote the sector and lobby federal and the state government. It is also published via a database of CMEs in Australia.

At the time of writing, this study is the only complete national database of CMEs and was recognised by the International Co-operative Alliance (ICA) as global best practice.

On 22 November 2019, Professor Mazzarol delivered the keynote address on *The State of the Co-operative and Mutual Enterprise Sector 2019* at the BCCM National Summit in Perth, Western Australia.

This research is supported by the Business Council of Co-operatives and Mutuals (BCCM)

Co-operative Federation of WA Centenary History

Project team: Winthrop Professor Tim Mazzarol (project leader; tim.mazzarol@uwa.edu.au), Dr Bruce Baskerville, Associate Professor Andrea Gaynor, Winthrop Professor Geoff Soutar

Collaborating organizations: UWA; CERU; UWA History Research Centre; Cooperative Federation of WA

This project is a collaboration between CERU, the UWA History Research Centre, and the Co-operative Federation of WA. It is focused on the development of a research book, celebrating the 100-year history of the Co-operative Federation of WA (1919-2019). This study commenced in 2018 and will continue to mid-2019, with the generation of a book that will be launched in August. The UWA Chancellor, Justice Robert French, will prepare a foreword for the book and will officially launch it at the celebration dinner at the University Club.

The project is also supported by the Co-operative Federation of WA as a potential foundation for a future ARC Linkage Grant project designed to map the history of the Co-operative and Mutual Enterprise sector in WA.

4: Cover of *Let Our Co-operative Spirit Stand: A centenary history of resilience and adaptation in the Co-operative Federation of Western Australia 1919-2019.*

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Co-operative and Mutual Strategic Development Program

Project team: Winthrop Professor Tim Mazzarol (project leader; tim.mazzarol@uwa.edu.au)

Collaborating organizations: AIM WA and UWA Business School Executive Education

Since 2014, CERU has worked with AIM WA – UWA Business School Executive Education, to deliver a specialised executive education program for the directors and senior managers of co-operative and mutual enterprises. This program has attracted strong interest from across Australia and internationally. A three day training program for 23 participants was conducted on 12-14 June 2019.

CERU Research into the CME Business Model

Project team: Winthrop Professor Tim Mazzarol (project leader; tim.mazzarol@uwa.edu.au)[1], Emeritus Professor Geoffrey Soutar[1], Professor Sophie Reboud[2], Professor Delwyn Clark[3], Dr. Elena Mamouni-Limnios[1]

Collaborating organizations: [1]UWA; [2]Burgundy Business School, Dijon France; [3]Waikato University, New Zealand

This research investigated the nature of the Co-operative and Mutual Enterprise (CME) business model and the factors that influence its competitiveness, sustainability, and economic and social outputs. This work was presented at the Australian and New Zealand Marketing Academy Annual Conference 2019 in Wellington, New Zealand.

This project was initially funded by ARC, now a range of other sources.

Agribusiness Innovation: A Pathway to Sustainable Development in Bangladesh

Project team: Professor Nazrul Islam (project leader; nazrul.islam@uwa.edu.au), Professor M Ismail Hossain, Hackett Professor Kadambot Siddique, Dr Amin Mugera, Professor Mohammed Quaddus, Dr Fazlul Rabbanee, Dr Elizabeth Jackson, Adjunct Professor Peter J Batt, Dr TM Tajul Islam

Collaborating organizations: UWA (IOA); Department of Economics, School of Business and Economics, North South University (NSU) Bangladesh; Bangladesh Agricultural Research Council (BARC) Krishi Gobeshona Foundation (KGF); Curtin University

North South University (NSU), in collaboration with the UWA Institute of Agriculture and Bangladesh Agricultural Research Council, organised an international symposium on "Agribusiness Innovation: A Pathway to Sustainable Development in Bangladesh." The symposium was held at the North South University Auditorium from 7-8 July 2019, and was inaugurated by Dr Mohammad Abdur Razzaque MP, the Honourable Minister for Agriculture, Government of the People's Republic of Bangladesh. More than 100 participants from business, academic, government leaders, and other industry stakeholders attended the symposium. The aim was to stimulate policy debate and strategy formulation for advancing agribusiness innovations and diffusion in Bangladesh by exploring the challenges and prospects of Agribusiness industries.

Participants presented scientific research papers, discussed and exchanged views in five technical sessions: (i) Commercialisation of Agriculture: Farm Production and Input Supply; (ii) Value Chain Initiatives: Post-Harvest Management, Storage, Transportation and Agro-Processing; (iii) Trade, Marketing and Agribusiness Finance; (iv) Agribusiness Capacity Building and Public Awareness; and (v) Role of Private Sector in Agribusiness Development (Industry Experience), and the inaugural and closing sessions of the two-day symposium. The UWA Institute of Agriculture was represented by Prof Kadambot Siddique, Dr Amin Mugera and Prof Nazrul Islam, who is currently with NSU as a Visiting Professor. Prof Siddique gave a talk on "Best practices of Agribusiness Development in Australia" while Dr Mugera gave a talk titled "Agribusiness Scholarship: What, Why, and How?". Prof Islam acted as the Convenor of the Symposium.

In the concluding and recommendation session, the Australian High Commissioner in Bangladesh Her Excellency Julia Niblett was present as a special guest. Later, the recommendations from the symposium were presented to the Honourable Minister for Agriculture, Dr Mohammad Abdur Razzaque MP, by Prof Nazrul Islam. The Honourable Minister expressed keen interest in the recommendations and in using them for effective policy making for agribusiness development in Bangladesh.

5: Prof Nazrul Islam (left) presenting the Recommendations to Dr Mohammad Abdur Razzaque (right) MP, the Honourable Minister for Agriculture in his Ministry office.

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

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

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

One in every four Filipinos are poor, and the rural area of Mindanao is home to ten of the most impoverished provinces in the country. Mindanao is also home to the top three fruit export industries—bananas, pineapples, and mangoes, but it is the smallholder farmers in these industries that are among the poor. Promoting inclusive agricultural development may offer a pathway out of poverty. Hence, this research will answer the following question: Are smallholder farmers capable of participating in modern agribusiness value chains, and if so, can access to modern markets through contract farming lead to better production performance and income?

First, we developed a framework in measuring comparative advantage and applied it to the tropical fruit exports from the Philippines. We calculated the annual comparative advantage performance of leading Philippine tropical fruit exports during the last 20 years, 1997-2016. Findings reveal that prodution on bananas, prepared and preserved pineapples, fresh and dried pineapples, pineapple juice and prepared and preserved mixed fruits had a comparative advantage. This may contribute to the formation of inclusive tropical fruit export value chains in the Philippines if the benefits derived from export markets are distributed to upstream actors including smallholder farmers.

Second, we developed an index to determine the likelihood of successful participation of farmers in modern value chains. The *Modern Market Participation Index* has five indicators, which comprise the five sustainable rural livelihood capitals—economic, physical, human, social, and natural. The index was applied to 292 banana and mango farmers in northern and southern Mindanao. We constructed the index using a composite indicator approach. Farmers who were participating in modern markets had significantly higher livelihood capitals and index value when compared to those participating in traditional markets. The determinants of modern market participation include farming experience, land productivity, productive assets, membership in a producer organisation, technical assistance, and road quality. The index can successfully predict 81.10% of correct cases. It can be used to identify areas for capacity building needed by farmers that could lead to a higher likelihood of their successful participation in modern markets.

Third, we compared the technical efficiency (TE) and production performance of farmers across various types of contract farming arrangements including individual contracts, cooperative contracts, and growers without a contract. Using a random sample of 186 farmers in Davao del Norte, Philippines, we applied propensity score matching to minimise the observable bias resulting from self-selection among farmers participating in contract farming. We employed both Data Envelopment Analysis (DEA) and Stochastic Frontier Production (SFP) function in calculating 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, primarily due to high export quality production. Getting into cooperative contracts will not only open the door for participating in export markets, but could also potentially improve smallholder farmers' income.

This research is supported by Australia Awards ACIAR John Allright Fellowship and University of the Philippines Mindanao.

6: Cavendish banana production in Mindanao, Philippines.

Exploring the nexus between farm capital structure and productivity in Western Australia

Project team: Dr. Amin Mugera, Prof Ross Kingwell and Mr. Steele West (project leader; steele.west@research.uwa.edu.au)

From the early 1990's to the present, the indebtedness of Australian farm businesses has risen approximately 400%. This rise in debt use by farm businesses has come against a backdrop of rising competition in export markets from producers such as Ukraine, Argentina, and Russia, increased climatic variability, slowing productivity, and declines in terms of trade. The objective of this project was to investigate how farm capital structure (i.e. how they finance their operations and investment) affects its productivity for a panel data of farm businesses in Western Australia, from 2002 to 2011.

In exploring the nexus between productivity and capital structure choice, our research offers a unique insight into the viability of farm businesses in our study on the impact of debt repayment obligations arising from the use of selected production inputs on the partial inefficiency of output production by farm businesses. The results show that debt repayment obligations affect smaller farm businesses more than larger farm businesses by being less efficient in resource use. Small farms have greater scope existing to reduce their input use and debt default risk. Our study further quantifies the output trade-offs to be made by lowering debt repayment obligations, with several farms exhibiting a negative trade-off between output and debt use, implying that these farm businesses could expand production by using less debt. The preliminary findings of our research were presented at the 2035 Ag Futures Conference, held in Perth in August 2019.

The research has been supported by an Australian Government Research Training Program Scholarship (Fee Offset).

Evaluating the Impact of Conservation Agriculture-based Sustainable Intensification on Farming Efficiency: The Case of Bangladesh

Project team: Mr Bruno Paz[1], Dr Atakelty Hailu[1], Assoc Prof Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]Bangladesh Agricultural Research Council; [3]Bangladesh Agricultural Research Institute; [4]CSIRO Ecosystems Sciences; [5]Curtin University of Technology; [6]RDRS Bangladesh; [7]CIMMYT

In an attempt to reduce food insecurity in the most vulnerable areas in the world, many organizations have delivered different programs based on Conservation Agriculture (CA). While many studies have found that CA increases farmers' productivity, little is known about the components of the productivity growth after adopting CA. Since CA is an intensive-knowledge technology, we expect that it has a positive effect on farmers' technical efficiency. Using cross-sectional farm-level data of 210 maize-farmers (123 CA adopters and 87 CA non-adopters) in Bangladesh, we measure the impact of CA adoption on farmers' technical efficiency using propensity score matching (PSM) and stochastic frontier analysis. The analysis showed that farmers that adopt conservation agriculture increased their productivity and technical efficiency by 5% and 7%, respectively. Thus, CA can be used as a strategy to reduce food insecurity in the poorest and least resilient areas in the world.

This research is supported by ACIAR.

7: On farm experiments on strip tillage.

8: Conservation agriculture field experiments in Bangladesh.

Farm productivity, adoption of and preferences for Climate-Smart Agricultural Practices in Nepal

Project team: Ms Sofina Maharjan[1], Prof Fay Rola-Rubzen[1] (project leader; fay.rola-rubzen@uwa.edu.au), Prof Ram Pandit[1], Prof Atakelty Hailu[1]

Collaborating organisations: [1]UWA

Nepal is facing multiple climatic shocks which have severe impacts on agriculture and food security. Climate-Smart Agricultural Practices (CSAPs) are one of the solutions to make agriculture resilient to climatic shocks and improve food security. Smallholder farmers adopt a combination of CSAPs to adapt to climatic shocks and minimise production risks. This study aims to examine the impact of CSAPs on productivity and technical efficiency of smallholder farms, assess the factors affecting the adoption of CSAPs among smallholders, examine farmers' preferences for CSAP schemes, and explore pros and cons of CSAPs among relevant policy/program developers and implementers in Nepal.

We employ a stochastic production frontier model, multinominal probit model, a discrete choice experiment, and an exploratory approach to study these objectives, respectively. Primary data collected from sample households from different districts (Chitwan, Rupendehi, Morang and Kaski) in 2016 and 2020 will be used in the study. This study contributes to a broader set of literature on the impact of CSAPs on productivity and technical efficiency in cereal production system using panel data, which has not been studied yet in South Asia. Other novel contributions of this study are the adoption of multiple CSAPs considering various factors including awareness of practices, access to service providers, attitude towards conservation, and awareness and perception of climate change, and also the study of farmers' preferences for CSAP schemes in South Asia. The findings of this study will provide empirical evidence for policymakers.

This research is supported by Australia Awards.

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

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

Collaborating organisations: [1]UWA (SAgE and IOA); [2]Agribusiness Research, Development and Extension Services, North Queensland; [3]Nepal Agricultural Research Council (NARC); [4]ACIAR

Realizing the need for assisting smallholder farmers in managing farming risks, the Government of Nepal has been implementing the Agriculture Insurance (AI) program since 2013, through a public-private-partnership model. However, despite a 75% subsidy in the premium, the adoption of crop insurance is negligible thus far. The design of the 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.

The study follows a mixed-methods research design involving both qualitative and quantitative methods. We are writing four research articles based on the findings of the study, with three papers already drafted. The first article establishes a broad context of farming risks, farmers' risk perception, attitude and existing risk management strategies using qualitative research methods. We found that drought, incidence of insects and diseases, higher production cost, lower crop production and lower output price were the major risks perceived by farmers. Farmers perceived that their own technical knowledge is the major intrinsic factor leading to farming risks. Additionally, uncertainty in timely availability of farm labour and agricultural inputs, and the monopolistic role of contractors in price determination of farm produce were the major extrinsic sources of farming risks. Farm diversification and mechanization of farm operations were the major risk management strategies practised by farmers. We also found that most of the farmers were risk averse as implied by their choice in simple hypothetical monetary lottery type question. However, most of them have not purchased crop insurance. This indicates that risk aversion does not readily translate to the adoption of crop insurance. Moreover, farmers' perceptions of risk, sources of risks and management strategies were similar across samples with different characteristics, which indicates that risk perception and responses in the farming domain are collective concerns of the society rather than idiosyncratic choices. In addition to exploring important information required for better farming risk management, we also validated cognitive mapping as an appropriate approach for studying farmers' risk perceptions and management decisions.

The other three articles triangulate the findings of the qualitative research through quantitative approaches, including Psychometric Scaling, Lottery-Choice Experiment (LCE) and Discrete Choice Experiment (DCE). The second article presents the findings on farmers' risk perceptions which are consistent with the findings presented in the first article. The third article presents the findings on the effect of various factors on farmers' risk attitude and the effect that this has on their risk management decisions. We found that the Nepali farmers were risk averse, in general. The variation in the farmers' risk-aversion is consistent with the variability in objective risk factors, as represented by drought risk vulnerability. Farmers' numeracy skill and landholding size had positive effects on their risk-aversion. Contrary to the prevalent stereotyping that women are more risk-averse than men, we found the opposite result. We also found that farmers' decisions on farm-mechanization, monetary saving, involvement in groups and cooperatives, production diversification, use of stress-tolerant crop varieties, accessing farm subsidies, and the adoption of insurance products, including crop insurance, were affected by their risk attitudes.

The fourth article presents the findings on the farmers' willingness to pay for crop insurance. We found premium rate and deductible had negative effects on the utility of crop insurance, while the sum insured had positive effect on the same. Such utility was unaffected by the type of insurance products, which implies that farmers are indifferent between the loss estimation methods. Among the attributes considered in the DCE, the sum insured had the highest marginal effect on the utility of insurance. Similarly, farmers' risk aversion, as revealed in the lottery-choice experiment, had a negative effect on the utility of status-quo, which indicates that the more risk averse the farmers are, the more willing they are to buy insurance. However, although about 60% of farmers stated their willingness to buy crop insurance, only 10% had already done so. Farmers' WTP for the existing crop insurance product was slightly lower than the current premium rate (after subsidy), which partly explains the demand-supply incongruence in the Nepali insurance market. Moreover, lack of awareness about the concept and benefits of insurance was the major reason for not buying a crop insurance product. The varied effects of sum insured, deductible, and farmers' risk aversion on the WTP suggest that there is potential for diversified insurance products that are built on farmers' preferences. Addressing other potential barriers related to farmers' awareness could also improve the adoption of crop insurance.

The findings of this study will be useful for the government agencies to develop appropriate farming risk management policy and support programs, for insurance companies to develop more saleable risk management products, and for farmers to optimize their welfare by making better farming and risk management decisions.

This research is supported by John Allwright Fellowship through ACIAR.

9: Researcher explaining the lottery-choice experiment to the participant.

10: Researcher doing a discrete-choice experiment.

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), Assistant Professor Ram Pandit[1], Mr Dinesh Babu Thapa Magar[1]

Collaborating organisations: [1]UWA

Overseas labour migration is increasingly becoming an intrinsic part of life for a large number of Nepalese households. More than 5 million Nepalese have migrated for overseas employment in the last two and a half decades, and the country is receiving large remittances equivalent to more than a quarter of the country's gross domestic product. Although an unprecedented level of remittance inflows, led by overseas labour migration, has contributed to poverty reduction significantly, the factors influencing overseas and return migration and its effects on the agriculture sector and smallholder farm-households is not yet adequately understood. This study is aimed at understanding the migration-remittance-agricultural development nexus and the reintegration of return migrants in Nepal. More precisely, this study aims to assess the determinants of migration decisions and destination choices, analyse overseas and return migration impacts on various agricultural outcomes, including productive investments, and assess occupational choices of return migrants.

Fieldwork for this study has already started in two purposively selected districts; one representing the terai and another representing the hill agro-ecology of Nepal. Primary data have been collected from about 700 households through household surveys in current overseas migrant, return migrant and non-migrant households, including 8 focus group discussions. The collected data will be analysed by applying econometric tools and techniques. The study findings are expected to contribute in understanding the migration-remittance-agriculture dynamics as well as shape appropriate strategies for maximizing the development impact of migration in Nepal.

This research is supported by UWA SIRF scholarship, UWA safety-net top up scholarship, and UWA Postgraduate Award.

11: Increasing fallow land in the hills of Nepal.

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), Dr Kalyan K Das[2], Dr Ram Datt[3], Mr Surya Adhikari[4], Dr Md Shakhawat Hossain[5], Mr Md Mamunur Rashid[6], Dr Roy Murray-Prior[7], Mr Jon Marx Sarmiento[1]

Collaborating organisations: [1]UWA; [2]Uttar Banga Krishi Viswavidyalaya; [3]Bihar Agricultural University; [4]Nepal Agricultural Research Council; [5]Bangladesh Agricultural Research Institute**;** [6]RDRS Bangladesh; [7]Agribiz RD&E Services

To alleviate the condition of the rural poor in South Asia, particularly in the Eastern Gangetic Plains, the Sustainable and Resilient Farming Systems Intensification (SRFSI) project was introduced. The goal of the project is to promote the use of sustainable agriculture-based systems intensification (CASI) technology to improve productivity, profitability and sustainability of small farmers while safeguarding the environment. In 2018, we conducted a socio-economic survey across Nepal, India and Bangladesh.

In this reporting period, we focused our efforts on understanding farm household decision making, impact of CASI adoption, and the determinants of adoption and disadoption of CASI technologies. Two reports have been submitted to ACIAR on 1) Farm household decision-making and risk perceptions of men and women farmers in the Eastern Gangetic Plains of South Asia and 2) Impact of Conservation Agriculture-based Sustainable Intensification (CASI) technologies among men and women farmers in the Eastern Gangetic Plains of South Asia.

We also presented a paper entitled '*Can Membership in Farmers' and Rural Producers' Organisations be a Pathway to Cultivate Gender Equality?*', during the 5th Global Science Conference on Climate-Smart Agriculture in Indonesia. In addition, we prepared the following papers for the AARES conference: 1) '*Abandonment of conservation agriculture technology after field trial: lessons from the Eastern Gangetic Plains experience*,' 2) '*Impact of conservation agriculture-based sustainable intensification technologies among men and women farmers in the Eastern Gangetic Plains*,' and 3) '*Explaining adoption of CASI technology in the Eastern Gangetic Plains: lessons learned*.'

This research is supported by ACIAR.

12: Field trials of conservation agriculture-based sustainable intensification technology.

13: Sitting with women farmers.

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

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

Collaborating organisations: [1]UWA; [2]Bihar Agricultural University; [3]Uttar Banga Krishi Viswavidyalaya; [4]Nepal Agricultural Research Council; [5]RDRS Bangladesh; [6]Rajshahi University; [7]University of New England

In recent years, the Governments of India, Nepal and Bangladesh have ramped up efforts to increase agricultural productivity and improve resilience of farm-households in the Eastern Gangetic Plains (EGP). As part of these efforts, various technologies have been introduced, but the adoption of these technologies have been variable and, often, low outside project sites. As decisions made by farm-households are central to the uptake of farming systems innovations, it is important to understand the decision making behaviour of farmers. This project aims to examine farm-household decision making with an end view of learning how to achieve better and faster adoption of technologies and farming systems innovations. Understanding the decision making behaviour of farm-households will allow for identification of actionable extension, and input and service delivery methods, that will lead to higher uptake of farming systems innovations and better farm management by men and women farmers.

Previous studies of farm-household decision analysis have been based on the neo classical assumption of economic utility maximization, but they have not been able to fully explain adoption behaviour. This project uses behavioural economics, which extends neo-classical economics to include other disciplines, particularly psychology and sociology. Given its nature, the project has been referred to as the Farmer Behaviour Insights Project (FBIP), reflecting the emphasis of the project. The goal of FBIP is to evaluate the value add of behavioural economics in understanding decision making by farm women and men, and use these behavioural insights to design/re-design, test and assess selected interventions in agricultural extension, input provision and agricultural service delivery in the Eastern Gangetic Plains.

During the first stage of the project, the team has trained project researchers in behavioural economics and research methodologies (12 training workshops). It has completed literature reviews of farmer decision-making and technology adoption. The team has also conducted focus group discussions (FGDs) to examine behavioural factors influencing decision making (31 FGDs participated by 351 farmers and service providers). FBIP has also conducted key informant interviews (KIIs) to explore, in-depth, behavioural factors influencing decision making (245 KIIs with farmers and service providers), and has developed communication materials and actively engaged in communicating project activities. It has completed two research reports (one on FGD and one on KII).

The project is at its initial stage. However, early indication based on the focus group discussions suggest that there is a strong potential for the FBIP project to contribute to the economic performance of farmers and service providers through improvements in adoption resulting from behavioural-informed designed interventions.

This research is supported by ACIAR.

14: Field Observation for Kidney Bean production in Salbani, Nepal.

15: Focus Group Discussion for Unpuddled Transplanted Rice production in Coochbehar, India.

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.

IOA News

IOA's broad range of activities are captured through the newsletter, *IOA News*. 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.

IOA News serves as a record of IOA's research activities and captures newly funded research projects, new staff and students, visitors to IOA and, importantly, a list of new peer-reviewed journals in agriculture and related areas.

Published three times per year – in April, August and December – *IOA News* is circulated widely in electronic format and hardcopy to over 6000 readers.

Online Presence

IOA's website, ioa.uwa.edu.au, provides an overview of the Institute'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 IOA homepage along with a repository of the latest media statements distributed. Documents such as the IOA Strategic Plan, annual research reports and newsletters can also be found on the website.

Throughout 2019, IOA sustained its social media presence on Twitter @IOA_UWA, and the number of followers grew to more than 900.

Visitors to IOA

Over sixty visitors from several countries were welcomed to IOA in 2019. Visitors included scientists from partner organisations, industry stakeholders and government representatives.

These interactions with staff and students are critical to knowledge sharing and to strengthening research links and collaborations both nationally and internationally.

For a full list of visitors to IOA during 2019, see www.ioa.uwa.edu.au/publications/newsletters

1: Dr Nik Callow shows students how to use a drone.

2: Engineering students with Professor Dilusha Silva (right) at the UWA Farm Ridgefield.

3: Patrick Beale (left) accepts the 2019 An Architecture of Necessity Award.

IOA Postgraduate Showcase: Frontiers in Agriculture

The IOA Postgraduate Showcase: Frontiers in Agriculture is an annual event which brings together some of UWA's best postgraduate students to share their research in agriculture and related areas with an audience of farmers, academics, scientists and representatives from industry and government.

This year, IOA celebrated the 13th consecutive event, with seven students from the UWA School of Agriculture and Environment, UWA School of Molecular Sciences, and UWA Law School presenting.

Professor Imelda Whelehan, Dean of the UWA Graduate Research School, gave the opening address, and The Hon Alannah MacTiernan MLC, Minister for Regional Development; Agriculture and Food; Ports Minister Assisting the Minister for State Development, Jobs and Trade, delivered a special address. The two sessions were chaired by Winthrop Professor Tim Mazzarol from the UWA Institute of Agriculture and UWA Business School, and Ms Tress Walmsley, CEO of InterGrain and member of the IOA Industry Advisory Board.

Ms Jeanette Jensen	Law and the Conflicting Interests of Stakeholders Involved with Managing Diffuse Source Pollution from Agriculture
Ms Madlen Kratz	The effects of nutrition on honey bee health and colony performance during crop pollination
Ms Toto Olita	Investigating the potential of insurance as a mechanism to enhance the performance of risky conservation tenders
Mr Luoyang Ding	Gene polymorphisms for temperament in sheep
Ms Roopali Bhoite	Genetic and genomic analysis of herbicide tolerance in Bread Wheat (*Triticum aestivum* L.)
Ms Alicea Garcia	Gendered subjectivities and climate change adaptation processes: How gendered dynamics of social inequality affect farmers' capacities to adapt to climate change in Ghana's Central Region
Dr Jo Wisdom	Modelling ecophysiological processes deterministic for fruit composition within a grapevine canopy

4: UWA PhD students shine at the 2019 Postgraduate Showcase. L-R: Professor Graeme Martin, Madlen Kratz, Luoyang Ding, Jeanette Jensen, Roopali Bhoite, Jo Wisdom, Alicea Garcia, Toto Olita, Professor Tim Mazzarol, Tress Walmsley, and Professor Kadambot Siddique.

4

IOA Industry Forum

Finding Common Ground: bringing food, fibre and ethics to the same table

More than 160 people including members of the agriculture industry, government agencies, media, academia and students came together in July for the 13th UWA Institute of Agriculture Industry Forum, to discuss how to rebuild trust between innovative primary producers and ethically informed consumers.

UWA's Deputy Vice-Chancellor (Research) Professor Robyn Owens officially opened the forum, and Dr Terry Enright, Leader of the IOA Industry Advisory Board, acted as the Master of Ceremonies.

Dr Nin Kirkham, Discipline Chair of Philosophy at UWA, gave the keynote address, highlighting historical and contemporary issues in the ethics of food and fibre production. She delved into various schools of philosophical thought around ethics in agriculture, with a particular focus on the treatment of animals. Dr Kirkham's discussion on ethics in agriculture provided a thought-provoking framework for the subsequent talks in the forum.

Deanna Lush, Managing Director of AgCommunicators and a farmer based in South Australia, shared insights from her winning essay in the Australian Farm Institute 2018 John Ralph Essay competition and from her Churchill Fellowship investigating trust in agriculture.

Professor Alan Tilbrook, Centre for Animal Science, Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, presented the goals and strategies of The Animal Welfare Collaborative.

CEO of Austral Fisheries, David Carter, shared insights from the company's initiatives aimed at ensuring all aspects of their fishing and trading operations are as environmentally sustainable as possible. For example, in 2016, Austral Fisheries became the first seafood company in the world to achieve Carbon Neutral certification through the Australian Government Carbon Neutral program.

The final presenters of the forum were Dr Holly Ludeman, a veterinarian and Director of the Sheep Collective, and Nicolle Jenkins, Managing Director of The Hub Marketing. Together, they spoke on the goals of The Sheep Collective.

The forum closed with a panel discussion and lively Q&A, facilitated by Professor Fiona Haslam-McKenzie, and followed by refreshments in The University Club of WA terraces.

The Industry Forum was supported by CSBP Fertilisers through the CSBP and Farmers Ltd Golden Jubilee of Agriculture Science Fellowship.

5: The 13th consecutive annual Industry Forum looked at how to rebuild trust between innovative primary producers and ethically informed consumers. L-R: Professor Alan Tilbrook, Deputy Vice-Chancellor (Research) Professor Robyn Owens, Ms Nicolle Jenkins, Dr Holly Ludeman, Dr Terry Enright, Dr Nin Kirkham, Ms Deanna Lush, Professor Fiona Haslam-McKenzie, Mr David Carter, and Professor Kadambot Siddique.

Dowerin Field Days

The IOA team joined the DPIRD exhibition at the Dowerin Field Days again in 2019, held on 28-29 August 2019.

PhD students Wesley Moss (UWA School of Engineering) and Mohammad Moinul Islam (UWA School of Agriculture and Environment) joined IOA Communications Officer Laura Skates and UWA Future Farm 2050 Project Officer Sandra Mata at the IOA display.

Engineering innovations for food production was a major theme of the IOA display this year. Visitors to the IOA booth could view a video of the Weed Chipper in action, see the results of the Seed Flamer technology for native seeds, and learn about the various ways UWA scientists are using drones in their research.

6: IOA team at Dowerin Field Days. L-R: PhD students Mohammad Moinul Islam and Wesley Moss, IOA Communicators Officer Laura Skates, and Future Farm 2050 Project Officer Sandra Mata.

GRDC Grains Research Update, Perth

UWA was once again well represented by staff and students at the annual Grains Research and Development Council (GRDC) Grains Research Update in Perth. Facilitated by the Grains Industry Association of WA (GIWA), over 600 attendees participated in the event at Crown Towers, Burswood from 25-26 February 2019.

Seven UWA students were awarded scholarships from the Australian Grains Innovation Capacity Building Project to attend the event, as part of their Careers in Grain initiative. These students are Estefania Poropat, Facundo Cortese, Enoch Wong, Jinyi Chen, Md Sultan Mia, Mohammad Golam Kibria, and Brenton Leske.

Several UWA researchers presented excellent talks during the conference, including

- Professor David Pannell: *A stocktake of knowledge on soil amelioration tools*
- Dr Ken Flower: *Ten years of different crop rotations in a no-tillage system – what happened to plant diseases and nematode pests*
- Dr Roberto Busi: *A 'focus farms' survey in the Kwinana West reveals herbicide resistance levels in champion farmers' paddocks: what's next?*
- Dr Andrew Guzzomi: *A response tyne for site-specific fallow weed control*

A copy of all presentations can be downloaded at www.giwa.org.au/2019researchupdates.

7: Guido Ramirez Caceres, Martina Badano Perez, and Estefania Poropat in front of the UWA Institute of Agriculture booth at GRDC Grains Research Updates.

UWA Future Farm 2050 Project: 2019 Highlights

The Future Farm 2050 Project (FF2050), based 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

In 2019, the FF2050 Project team hosted more than 400 visitors, including farmers, industry representatives, Shire of Pingelly Councillors, alumni and volunteers on UWA Farm Ridgefield. The team also hosted students and academics from a wide variety of institutions such as Murdoch University, Griffith University, Notre Dame University, United World College of South East Asia, AAUN, Lanzhou University, Instituto Nacional de Investigacion Agropecuaria (INIA), Institute for Agricultural Technology Argentina (INTA), Rothampstead Research Station UK, and the Gansu Institute of Scientific and Technical Information China.

We engaged with the wider community and agriculture industry at events such as the Dowerin Field Days, the Facey Group Women in Agriculture Day, GRDC Grains Research Updates, the Muresk Institute FarmSmart Showcase, Techspo, the Regenerative Agriculture Conference and UWA Open Day.

Our strong online presence allows us to engage with people all around the world. The Massive Open Online Course (MOOC) '*Discover Best Practice Farming for a Sustainable 2050*' attracted a further 4600 enrolments in 2019, reaching a total of 8629 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.

In January, Professor Graeme Martin, FF2050 Project Leader, was admitted into the *Academie d'Agriculture de France* (AAF). The AAF is directly descended from the Société D'Agriculture de la Généralité de Paris, founded in 1761 by Louis XV. Professor Martin joins a few other Australians in this prestigious organisation, such as UWA Soil Scientist Professor Jim Quirk. After his induction Professor Martin gave a presentation on "La Ferme du Futur 2050 (FF2050)" which led to a discussion of a possible French partner in the *Global Farm Platform*, the international network of future farms that includes FF2050. Two farms in France have since joined the network.

Throughout the year, thirty-seven media stories were published, nine international presentations about the FF2050 project were given and 12 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 FF2050 project provides an excellent platform for practical field experience.

Fifty undergraduate students studying Pasture and Livestock Systems and 72 students studying Soil Science visited the farm, as did six Masters students studying Animal Production Systems.

Four postgraduate research students studying agriculture and related topics conducted components of their research on the farm. Their research topics were relevant to the FF2050 vision: *Fate of pre-emergence herbicides intercepted by residues in conservation agriculture systems* (Yaseen Khalil); *Restoring degraded landscapes - the role of digging mammals on seedling recruitment* (Gabrielle Beca); *Mapping moisture in variable-textured soils of Western Australian Wheatbelt by non-invasive methods* (Hira Shaukat); *Characterisation of the spatial distribution of soil properties with an alternative perennial forage shrub plantation with relation to implications for improvements in soil health and soil management* (Thomas Ferguson).

As part of the Master of International Water Management, a group of students from Griffith University, Queensland visited UWA. Adjunct Professors Jeff Camkin and Susana Neto took the students to UWA Farm Ridgefield where they learnt about water management in dryland broadacre agricultural systems, with a focus on the context of climate change.

Enthusing the next generation of scientists, UWA Professors and farm staff welcomed 25 Year 9 Specialist Agriculture students and teachers from Kelmscott Senior High School, and 22 Penrhos ATAR Geography students and teachers. The Kelmscott students were particularly excited about seeing the Ausplow DBS Airseeder in action. In addition, Professor Graeme Martin used FF2050 as a foundation for supporting the Primary Extension and Challenge (PEAC) program at two Perth centres, with 28 Year 5 and 6 students undertaking courses in Global Food Security. He also presented a session on *Food Security for a Hungry Planet* to 25 secondary teachers at the 2019 Humanities and Social Science Conference in Perth.

International students are also a common sight at FF2050. From the USA, 18 students from Notre Dame University visited with Associate Professor Martin Forsey (UWA Sociology and Anthropology). From Singapore, 55 Year 12 students from United World College of South East Asia visited with their Professor Mireille Couture, Head of Environmental Systems and Societies.

Contributing to the local community

The future of agriculture depends on people as well as technology so the FF2050 Project includes the social sciences and health sciences.

A *Community Outreach Group* (COG) was formed by Dr Susan Bailey (UWA Adjunct Lecturer) and Mr Ron Jones (Project Manager, UWA Office of Research Enterprise). Dr Bailey is forging links between UWA staff and the Pingelly community through, for example, the Pingelly Aboriginal Progress Association (PAPA), the Pingelly Shire, and the Pingelly Community Resource Centre (CRC). Dr Bailey has been working to ensure that UWA collaborates with Noongar communities in a culturally safe environment so they can work together into the future.

The *UWA Staying in Place Living Lab and Virtual Village* project was brought to Pingelly by Associate Professor Loretta Baldassar and Dr Lukasz Krzyzowski, both from the Sociology and Anthropology discipline within UWA's School of Social Sciences. They met with the *Pingelly Somerset Alliance* to discuss the development of a project that aims to establish a digital network to support elderly people who wish to retire in Pingelly. International research has shown that when an individual's support network falls below three people, then health outcomes rapidly deteriorate. The goal is for these people to lead full lives amongst family and friends, rather than move to the city.

UWA Honorary Research Fellow Patrick Beale who designed the Farm Manager's House on UWA Farm Ridgefield continued to help support the Pingelly community by designing the Pingelly Recreation and Cultural Centre (PRACC). The PRACC is a $9 m sports and entertainment complex, bringing together lawn bowls, sports fields and ball courts into a centre with common food and bar facilities. It is the largest wooden construction built in the southern hemisphere since WWII. The PRACC has transformed the town's capacity to support sports clubs, host competitions and provide casual social venues and activities for Pingelly and surrounding communities. He was awarded the *2019 Architect of Necessity Award* from the Virserums Kronsthall in Sweden for the design. The PRACC was also a finalist in the World Architecture Festival: Best Use of Certified Timber 2019 Sports *Facilities* and has won three Australian Timber Design Awards in Melbourne.

The *International Artist in Residence Program Spaced 4: Rural Utopias* was launched in 2019, with UWA artist Dr Mike Bianco leading one of the projects in Pingelly, with support from UWA Farm Ridgefield. An outline of the project was presented to the Pingelly CRC network and FF2050 project team, followed by a tour of UWA Farm Ridgefield, with International Art Space Director Ms Soula Veyradier.

The FF2050 project team participated in a workshop run by the Forum Advocating Cultural and Eco-Tourism (FACET), hosted by the Department of Biodiversity, Conservation and Attractions. The aim of the workshop was to discuss and promote astro-tourism through the WA Wheatbelt. UWA Farm Ridgefield has hosted two very successful 'Astrofest' events in the past, during which local and city people had an opportunity to peer at the stars through telescopes that serious amateurs bring down from Perth. These events bring SciTech and ICRAR to regional communities.

Engineering innovations for food production

Agricultural Engineering activities continue to develop on the farm, including a commercial engagement with AusPlow Farming Systems, and opportunities for partnerships in research with Roesner Engineering and CSBP.

Data, sensors and robotics are the new frontier, and their essential interoperability hinges on the availability of high-speed communications infrastructure. At a more pragmatic level, mobile phone coverage is needed for occupational health and safety, and farm-gate security. The security issue was taken on as a research project by UWA Masters students in their course, Electrical and Engineering Design. They scoped the farm landscape and drafted designs for security cameras connected by Wi-Fi access. This opportunity provided real-life problem solving on a large scale for the students, who embraced the challenge with enthusiasm and creativity.

Negotiations with Telstra will see a communications tower placed on the farm in 2020, providing mobile-phone coverage across the entire farm, while also enabling high-speed data connectivity to the outside world. This provides essential R&D infrastructure for the next revolution in agriculture as well as engineering solutions for the management of landscape and catchment.

Animal production systems

The *Merino Lifetime Productivity* (MLP) project has continued, with the latest data analysis presented to 60 farmers, industry representatives and researchers at the annual Field Day in October. Issues discussed included economic evaluation of the sires and sire types from estimates of feed intake, body composition and lifetime productivity of ewes and wethers. This project is funded through Australian Wool Innovation and involves collaboration with Murdoch University and leaders in the Merino industry.

Farmer-friendly performance indicators for sheep production systems was the main reason for a visit by Andy Jones, a PhD Student from the University of Bristol; Rothamsted Research. Mr Jones used his Stapledon Travel Fellowship to look into a wide variety of sheep farming systems in Australia and New Zealand. He works at the Rothamsted Research North Wyke Farm Platform that, along with FF2050, is one of the founding members of the *Global Farm Platform* supported by the Worldwide Universities Network (WUN).

Media Statements

IOA continued communicating its research outcomes to the general public through the media by distributing media statements in agriculture and related areas throughout 2019. A substantial amount of media coverage was generated in local, rural, national and international print, broadcast and online media.

Date	Title
28 February	Plant scientist awarded Nancy Millis Medal for Women in Science
1 March	Best practices for agriculture under climate change
26 March	Discovery to help wheat cope with salty soils
10 April	Students inspired by agricultural science at UWA Future Farm
15 April	UWA researchers helping Australian sheep producers tackle high-oestrogen clovers
30 April	Breakthrough in high-yield drought-resilient chickpeas
21 May	Call for greater transparency in gluten free testing
17 June	Stressed sheep fleeced by their genes
11 July	Forum to bring food, fibre and ethics to the same table
22 July	Wool odour could be key to protecting sheep from flystrike
13 August	Mountain Agriculture vital to ending hunger
20 August	Breakthrough in disease resistance for Brassica crops
26 August	The UWA Institute of Agriculture releases Annual Research Report 2018
2 September	Forest loss in Brazil contributing to rising temperatures
3 September	First pea genome to help improve crops of the future
12 September	Study finds crop fungus not linked to malnutrition in Timor-Leste
23 September	Machine learning aims to improve water management in dryland agricultural ecosystems
1 October	Agricultural expert receives highest honour from People's Republic of China
8 October	Integrated management approaches to combat plant virus diseases
24 October	Study digs up one billion years of green plant evolution
24 October	New Joint Venture to improve annual legume breeding
7 November	Weed chipper recognised in WA Innovator of the Year awards
29 November	Herbicide tolerant wheat to improve productivity
10 December	Research to improve broadacre farm profitability

Public Lectures and Special Seminars

Date	Presenter	Organisation	Title
1 July	Dr Ashwani Pareek	School of Life Sciences, Jawaharlal Nehru University	Designing crops for dry and saline soils
1 July	Dr Sneh Lata-Singla Pareek	Plant Stress Biology, International Centre for Genetic Engineering and Biotechnology	Feed the future: developing high yielding, multiple stress tolerant rice
14 November	Dr Rashmi Yadav	Indian Council of Agricultural Research National Bureau of Plant Genetic Resources (ICAR-NBPGR)	Characterisation, evaluation and utilisation of rapeseed - mustard crops in India
19 November	Professor Gabrielle Persley AM	Global Change Institute, University of Queensland	**Hector & Andrew Stewart Memorial Lecture 2019** Australia's role in International Agricultural Research
10 December	Dr Laurent Ameglio	Managing Director of EXIGE, Managing Partner of SkyBorg, and CEO of GyroLAG	Developments in airborne geophysics and geomatics to map variability of soil properties

Awards and industry recognition

Name	Award
Prof Jacqui Batley	Nancy Millis Medal for Women in Science, from the Australian Academy of Science
Adj/Prof Rex Scaramuzzi	Marshall Medal, from the Society for Reproduction and Fertility (UK), the highest honour that can be awarded in the field
Prof Graeme Martin	Inducted into the Academie d'Agriculture de France
Hackett Prof Kadambot Siddique	Friendship Award from Chinese Central Government
Hackett Prof Kadambot Siddique	Excellence Award for Community Services, World Malayalee Council
Dr Michael Walsh and Dr John Broster	Weed Science Society of Australia Outstanding Paper Award – Weed Technology
Prof Hans Lambers	Honorary Professor from Jiangxi Agricultural University
Prof Hans Lambers	ISRR Dundee Medal for distinguished root research
Dr Deirdre Gleeson	Science Faculty 2019 Award for Excellence in Postgraduate Research Supervision
Prof Petra Tschakert	Piers Sellers Prize, from the Priestley International Centre for Climate, for a world leading contribution to solution focused climate research
Dr Philipp Bayer	Finalist for Woodside Early Career Scientist of the Year
Jin Yi Chen and Ms Mary-Ann Lowe	Honourable mention from the Dean of Graduate Research School for outstanding PhD theses
Dr Andrew Guzzomi	Semi-finalist in the Emerging Innovation category of the 2019 WA Innovator of the Year program, for "The Weed Chipper"
Prof Kadambot Siddique	Distinguished Visiting Professor from Shenyang Agricultural University, China
Prof Kadambot Siddique	Visiting Professor from Northwest Agricultural and Forestry University, Yangling, China
Mr Jorge Silva	Buy West East Best Kim Chance Fellowship Award
Dr Muhammad Khalid Bashir (UWA alumnus)	Best Young Research Scholar Award
Ms Kirsty Smith (UWA Alumnus)	Grains Research and Development Corporation (GRDC) Western Region Emerging Leader Award
Mr Patrick Beale	2019 An Architecture of Necessity Award
Dr Andrew Guzzomi	2019 UWA nominee for the Australian Awards for University Teaching (AAUT) for Outstanding Contributions to Student Learning
Dr Andrew Guzzomi and the Weed Chipper team	Rio Tinto Emerging Innovation award category at the 2019 WA Innovator of the Year awards
Mr Omar Anwar	Western Australian Government Science Industry PhD Fellowship, partnering with Elixir Honey
Ms Katarina Doughty	Western Australian Government Science Industry PhD Fellowship, partnering with Aquatic Life Industries
Ms Gereltsetseg Enkhbat	Western Australian Government Science Industry PhD Fellowship, partnering with PGW Seeds
Ms Soodeh Tirnaz	Mike Carroll Travelling Fellowship
Ms Soodeh Tirnaz	Craig Atkins Travel Award in Botany
Ms Soodeh Tirnaz	Underwood PhD Scholarship
Mr Suyog Subedi	Mike Carroll Travelling Fellowship
Ms Nooshin Shahbazi	Calenup Postgraduate Research Fund
Mr Michael Young	Sir Eric Smart Honours Project Scholarship
Ms Justina Serrano	Sir Eric Smart Masters Project Scholarship

New postgraduate research students

Student Name	Topic	School	Supervisor(s)	Funding Body
Omnia M. M. H. Arief	*Ecophysiological* studies on *Lupinus albus* L.	Biological Sciences and IOA	Prof Hans Lambers	Mission Sector, Ministry of Higher Education, Egypt
Sofina Maharjan	Payment for Environmental Services as an instrument for facilitating adoption of Conservation Agricultural Practices	Agriculture and Environment and IOA	Assoc/Prof Fay Rola-Rubzen and Dr Ram Pandit	John Australia Awards/ Alwright Fellowship
Doraid Esho Amanoel Alkhishaybi	Grazing Saltbush (*Atriplex spp.*) to mitigate loss in sheep productivity caused by vitamin E and Selenium deficiencies	Agriculture and Environment and IOA	Dr Dominique Blache	Hackett Postgraduate Scholarships
Gereltsetseg Enkhbat	Diversity of *Trifolium subterraneum ssp. yanninicum* for waterlogging tolerance and morphological traits	Agriculture and Environment and IOA	Prof William Erskine, Prof Megan Ryan, Dr Phillip Nichols, Prof Yoshiaki Inukai and A/Prof Takao Oi (Nagoya University)	RTP scholarship
Robyn Anderson	Using Deep Learning for trait prediction in *Brassica napus* (Canola)	Biological Sciences	Prof Dave Edwards, Prof Jacqueline Batley, Dr Philipp Bayer, Prof Mohammed Bennamoun and Dr Kosala Ranathunge	RTP
Cassandria Tay Fernandez	Assessing gene presence/absence diversity within and across legume species by constructing a legume pan pangenome	Biological Sciences	Prof Dave Edwards, Dr Philipp Bayer and Prof Jacqueline Batley	RTP and ARC top-up
Jacob Marsh	Soybean genomic variation analysis in order to identify candidate alleles for targeted introduction into cultivar lines	Biological Sciences	Prof Dave Edwards, Dr Philipp Bayer, Prof Jacqueline Batley and Dr Kosala Ranathunge	RTP
Monica Furaste Danilevicz	Deep learning application in plants stress and disease detection	Biological Sciences	Prof Dave Edwards, Prof Mohammed Bennamoun, Prof Jacqueline Batley and Dr Philipp Bayer	RTP and Forrest Research Foundation
Aldrin Cantila	Exploring the genetic potential in *Brassica napus* cultivars and its wild relatives for Blackleg resistance genes	Biological Sciences	Prof Jacqueline Batley, Prof Dave Edwards, Prof Wallace Cowling and Dr Philipp Bayer	RTP, GRDC
James Kelly	The application of portable spectroscopy for on-site wheat grain quality analysis and varietal identification	Molecular Sciences	Dr Nic Taylor and Dr Bjorn Bohman	RTP and GRDC Research Scholarship
Junrey C. Amas	Identification of Resistance Genes against Blackleg disease of Canola	Biological Sciences	Prof Jacqueline Batley; Prof Wallace Cowling; Prof Dave Edwards and Dr Philipp Bayer	UIFS - UWA International Fee Scholarship; University Postgraduate Award (International Students)
Tingting Wu	Identification novel resistance gene against Blackleg disease in *Brassica napus* cultivar and wild species	Biological Sciences	Prof Jacqueline Batley; Prof Wallace Cowling; Prof Dave Edwards and Dr Philipp Bayer	CSC-UWA Scholarship
Linh Ton	CRISPR/Cas9 platform for controlling viral pathogens in Chilli plants	Biological Sciences	Prof Jacqueline Batley; Prof Dave Edwards and Dr Philipp Bayer	UIFS - UWA International Fee Scholarship; University Postgraduate Award (International Students)

New research grants awarded in 2019

Title	Funding Period	Funding Body	Supervisors
Building capacity to enhance farmer's capabilities to address the challenges of climate change using Climate Smart Agriculture strategies	2019-2020	Asia Pacific Network for Global Change Research (APN)	Dr Nuthan Kaushik (Amity University, New Delhi), Prof Kadambot Siddique
Comparisons of locally produced premium sulphate of potash and imported potash fertilisers on yield, quality of grain and soil biology	2019-2020	Australian Potash Ltd	Prof Kadambot Siddique, Dr Zakaria Solaiman
Ground-truthing field expression and value of new flowering time genes in lupins for Western Australia	2019-2020	COGGO	Prof Wallace Cowling
Fit-for-purpose biochar to improve efficiency in ruminants	2019-2021	CSIRO ex MLA	Prof Philip Vercoe, Dr Zorica Durmic, Miss Kobporn Vadhanabhuti
Postdoc Research Fellowship: Maximising crops and minimising weeds with smart phase farming	2018-2021	GRDC	Dr Michael Ashworth, Dr Yaseen Khalil
Phase 2: Maximising the reproductive potential of the meat sheep industry by eliminating high oestrogen clovers, more live lambs on the ground	2019-2021	MLA Donor Company	Mr Kevin Foster, A/Prof Megan Ryan, Prof Philip Vercoe, Dr Zorica Durmic, Dr Dominique Blache, Prof Graeme Martin, Dr Caitlin Wyrwoll
Rio Tinto Australia-Japan Collaboration Program Grants - Understanding the role of glutathione S- transferase: an important enzyme to protect crops and fight weeds	2019	Foundation for Australia-Japan Studies (FAJS)	Dr Roberto Busi, Dr Danica Goggin, A/ Prof Satoshi Iwakami, A/Prof Todd Gaines, Dr Eric Patterson
Exploiting the Potential of a Novel Fungal Biofertiliser	2019-2021	GRDC	Dr Khalil Kariman, Prof Zdenko Rengel, Dr Craig Scanlan
Program 3: Towards effective control of blackleg of canola: Identification of novel sources of blackleg resistance genes	2019-2022	GRDC	Prof Jacqueline Batley, Prof David Edwards, Prof Martin Barbetti
PROC-9175855 Program 2 – Towards effective control of blackleg pathogen of canola - Coordinating International Blackleg R&D	2018-2023	GRDC	A Van de Wouw, Prof Jacqueline Batley
Institutions to Support Intensification, Integrated Decision Making and Inclusiveness in Agriculture in the East Gangetic Plain	2018-2019	University of South Australia ex ACIAR	A/Prof Michael Burton
Synergising Pedodiversity and Biodiversity to Secure Soil Functionality	2019-2021	University of Sydney Ex ARC Discovery Projects	Prof Alexander McBratney, Prof Anthony O'Donnell, Prof Budiman Minasny
Improving canola heat tolerance – a coordinated multidisciplinary approach	2019 - 2023	GRDC	Dr Sheng Chen, Prof Wallace Cowling and Prof Kadambot Siddique
A new Western Australian flavonoid-rich apple, BravoTM, and vascular health	2019	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, Ms 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

Title	Funding Period	Funding Body	Supervisors
Soil sulfur influence on microorganisms	2019	DPIRD	Dr Deirdre Gleeson
Proof of concept for Flash Farming and Benchmarking	2019	DPIRD	Prof Philip Vercoe, 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, E/Prof Lynette Abbott
Who's who in the plant gene world?	2020-2022	ARC Discovery Project	Prof Dave Edwards, 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, 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, Assoc/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, Prof John Tarlton
Rapid breeding for reduced cooking time and enhanced nutritional quality in common beans (*Phaseolous vulgaris*)	2019-2023	ACIAR	Prof Wallace Cowling, 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, Prof Kadambot Siddique, 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, 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, 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	Asst/Prof Ram Pandit, Dr Amin Mugera, Mr Asjad Sheikh

Memoranda of Understanding

Title	Date Signed
Institute of Scientific and Technical Information of Gansu (ISTIG)	3 January 2019
Amity University	20 February 2019
Northwest A&F University	15 August 2019
North South University	19 September 2019
Shenyang Agricultural University	5 November 2019
Universidad Nacional de Cordoba	3 December 2019
CCS Haryana Agricultural Univesity	16 December 2019

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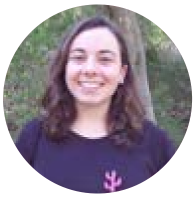

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Theme Leaders

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Industry Advisory Board (IAB)

The IAB provides the Institute 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

Mr Rod Birch
Farmer

Dr Dawson Bradford
Farmer

Mr Philip Gardiner
Farmer

Dr Bruce Mullan
Director Sheep Industry Development, Grains and Livestock Industries, DPIRD

Prof Tony O'Donnell
Executive Dean
Faculty of Science, UWA

Dr Michael Robertson
Deputy Director, CSIRO

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

Mr Simon Stead
Director, CBH Group

Mr Ben Sudlow
Manager, Fertiliser Sales and Marketing, CSBP

Ms Tress Walmsley
CEO, InterGrain

Ms Dani Whyte (from April 2019)
Agronomist, Planfarm & Vice President, AAAC(WA)

Mr Neil Young
Farmer

Mrs Annie Macnab (Executive Officer)
Finance Officer, IOA, UWA

Ms Sam Carlson (Executive Officer)
Business Manager, IOA, UWA

2019 Publications

In 2019, researchers affiliated with the UWA Institute of Agriculture published more than 270 peer-reviewed journal papers, as well as several books, book chapters, and reports. Peer Reviewed Journals

Adams IP, Fribourg C, Fox A, Boonham N, Jones RAC (2019). Complete coding sequence of *Andean Potato Mottle Virus* from a 40-year-old sample from Peru. *Microbiology Resource Announcements* **8**(40): e00871-19.

Ahmed W, Xia Y, Li R, Bai G, Siddique KHM and Guo P (2019). Non-coding RNAs: Functional roles in the regulation of stress response in *Brassica* crops. *Genomics* doi: 10.1016/j.ygeno.2019.08.011

Ahmed W, Xia Y, Zhang H, Li R, Bai G, Siddique KHM and Guo P (2019). Identification of conserved and novel miRNAs responsive to heat stress in flowering Chinese cabbage using high-throughput sequencing. *Scientific Reports* **9**: 14922.

Al-Lami HF, You MP and Barbetti MJ (2019). Incidence, pathogenicity and diversity of *Alternaria spp.* associated with alternaria leaf spot of canola (*Brassica napus*) in Australia. *Plant Pathology* **68**: 492-503.

Al-lami HF, You MP and Barbetti MJ (2019). Role of foliage component and host age on severity of Alternaria leaf spot (caused by *Alternaria japonica* and *A. brassicae*) in canola (*Brassica napus*) and mustard (*B. juncea*) and yield loss in canola. *Crop and Pasture Science* **70**: 969-980.

Al-Saedi R, Smettem K and Siddique KHM (2019). The impact of biodegradable carbon sources on microbial clogging of vertical up-flow sand filters treating inorganic nitrogen wastewater. *Science of The Total Environment* **691**: 360-366.

Anderson R, Edwards D, Batley J and Bayer PE (2019). Genome-wide association studies in plants. *eLS.*

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Acronyms

AARES Australasian Agricultural and Resource Economics Society
ACIAR Australian Centre for International Agricultural Research
ACMEI Australian Co-operative and Mutual Enterprise Index
ACT Australian Capital Territory
AGT Australian Grain Technologies
AHRI Australian Herbicide Resistance Initiative
AIA Ag Institute of Australia
AI Artificial Intelligence
AI-Com Agricultural innovations for communities
AIM Australian Institute of Management
ALBA Annual Legume Breeding Australia
AM Member of the Order of 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)
CDIIS Commonwealth Department of Industry, Innovation and Science
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
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
EU European Union
FAAS Fellow of the Australian Academy of Science
FAIA Fellow of the Australian Institute of Agriculture
FAIR Findable, Accessible, Interoperable, Reusable
FAO Food and Agriculture Organization of the United Nations
FBIP The Farmer Behaviour Insights Project
FEC Faecal Egg Count
FF2050 UWA Future Farm 2050 Project, UWA Farm Ridgefield
FFLI Food, Fibre and Land International
FGDs Focus Group Discussion
FISPP Fellow of the Indian Society for Plant Physiology
FNAAS Foreign Fellow of the Indian National Academy of Agricultural Sciences
FTL Forage Tree Legumes
FTSE Fellow of the Australian Academy of Technological Sciences and Engineering
GBS Genotyping by sequencing
GHG Greenhouse Gas
GIWA Grains Industry Association of WA
GO Gene ontology
GPS Global Positioning System
GRDC Grains Research and Development Corporation
HWSC Harvest Weed Seed Control
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
IoT Internet of Things
ISABU Institut des Sciences Agronomiques du Burundi
IT Information Technology
IWA International Water Association
IWC International Water Centre, Griffith University
IWYP International Wheat Yield Partnership
JIC John Innes Centre
KARLO Kenya Agricultural and Livestock Research Organization, Kakamega, Kenya
KGF Krishi Gobeshona Foundation
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
MLI Meat and Livestock Industry
MOOC Massive Open Online Course
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
PEAC Primary Extension and Challenge
PUE P Use Efficiency
QLD Queensland
QTL Quantitative trait locus
RADB Rwanda Agriculture and Animal Resources Development Board, Kigali, Rwanda
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
RNA Ribonucleic Acid
RTP Research Training Program scholarship
SA South Australia
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, Maruku, Bukoba, Tanzania
UAF University of Agriculture, Faisalabad, Pakistan
UAV Unmanned aerial vehicle
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
UWA The University of Western Australia
VIC Victoria
WA Western Australia
WUN Worldwide Universities Network