THE UNIVERSITY OF WESTERN AUSTRALIA

Institute of Agriculture

Annual Research Report

2018

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: Peter Maloney, DPIRD

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The UWA Institute of Agriculture Annual Research Report 2018

Director’s overview

On behalf of The University of Western Australia, I am pleased to present the 2018 Annual Research Report for The UWA Institute of Agriculture.

In 2018, The UWA Institute of Agriculture (IOA) continued to collaborate across the 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. Collaborative and multi-disciplinary research 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 for Food Production; and Agribusiness Ecosystems. IOA researchers published more than 200 journal articles, book chapters, and reports in 2018, spanning a wide range of topics, from the health benefits of apples, to disease resistance genes in canola, to new technologies for managing weeds on farm.

As always, a major focus for 2018 was effective communication of agricultural research and training activities at UWA, and deepening our engagement with industry, farmer groups, collaborators, funding bodies and alumni. A total of 23 media statements were distributed throughout the year generating coverage in the regional and international agricultural press. Annual engagement activities such as the public lecture series, the Postgraduate Showcase and the Industry Forum were well received by our key stakeholders and community at large. The Massive Open Online Course (MOOC) *Discover Best-Practice Farming for a Sustainable 2050*, which launched October 2017, saw an impressive 3160 participants enrol in 2018, resulting in 4000 enrolments since the MOOC’s inception.

More than 600 students, academics and industry leaders visited the UWA Farm in 2018. The UWA Future Farm project hosted *Pingelly Astrofest 2018* in conjunction with the International Centre for Radio Astronomy Research (ICRAR) and SciTech, and a field tour for around 40 delegates of Australia’s premier lamb industry expo, *LambEx*. 2018 also saw the official opening of the *Pingelly Recreation and Cultural Centre* and the new *Student Learning Hub*.

UWA remained in the top 100 position in global rankings in 2018, including the Academic Ranking of World Universities (93), Quacquarelli Symonds (91) and US News & World (81). I was pleased to see that UWA’s strong position in Agriculture remained at 1st in Australia and 14th in the world in the 2018 Academic Ranking of World Universities. Committed partners, dedicated staff, and strong support from funding bodies and industry have made these significant achievements possible.

IOA welcomes and looks forward to collaborating with the UWA Public Policy Institute, which was established in 2018 to provide research and advice in the area of public policy development in Western Australia, Australia and beyond our shores.

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 dedicated support and assistance throughout 2018.

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 has enjoyed working with the institute again this year towards the common goal of advancing the agricultural and natural resource management sectors in Western Australia and beyond.

Each year the Board contributes to the annual IOA Industry Forum, which this year focused on Disruptive technologies: *a new revolution in agriculture*. The forum featured research from the new IOA theme *Engineering for Food Production* with a talk by Dr Andrew Guzzomi, alongside talks from leading farmers and industry experts. The forum delved into how remote sensing, robotics, artificial intelligence and BigData are affecting the food production value chain, and was well received by the agriculture industry and community.

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.

In 2018, the IAB welcomed Mr Simon Stead, Director, CBH Group, who runs a mixed sheep, cattle and cropping operation in Cascade and Dalyup in the Esperance port zone. Mr Stead worked for Wesfarmers and has a long involvement with the South East Premium Wheat Growers Association (SEPWA), and is a founding member and past chair of the Association for Sheep Husbandry, Excellence, Evaluation and Production (ASHEEP).

Simon adds to the diversity of skills represented on the IAB, including members from the livestock and cropping industries together with plant breeding, CSIRO and DPIRD. We will continue to explore opportunities to renew and expand the skills of the IAB to ensure capacity required to support the IOA.

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, Director, Hackett Professor Kadambot Siddique and his team, and all those who have supported IOA in its achievements in 2018.

Dr Terry Enright
Chair of the IOA Industry Advisory Board

1

Crops, Roots and Rhizosphere

Theme leaders

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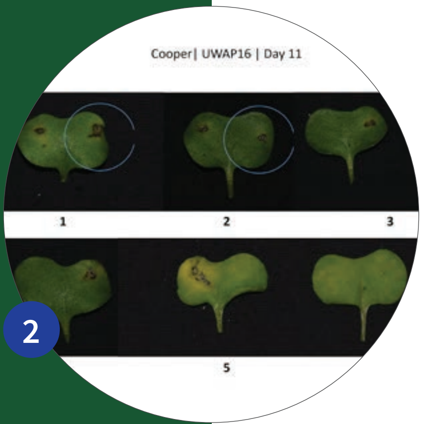
The Crops, Roots and Rhizosphere theme covers all aspects of crop production, both aboveground and belowground. Participants in the theme work across a broad scale from genomics and plant physiology to crop breeding and field agronomy. Projects are generally multidisciplinary and involve collaboration 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 inclusion of postgraduate students, commonly Masters by coursework project students and PhD students.

As is evident from the projects included in our section of 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 targeted both at the dryland farming systems of WA and southern Australia more generally, as well as to northern Australia and our neighbours in Asia including China, Timor Leste, Bangladesh, India and Vietnam.

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 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. We also 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.

1



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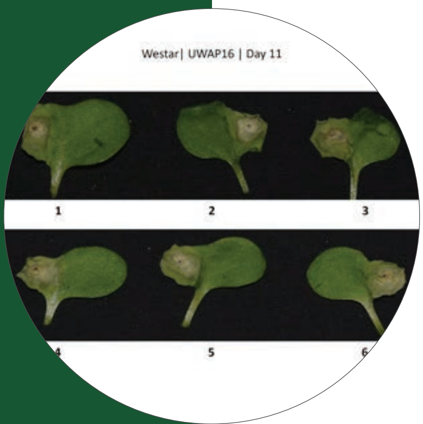
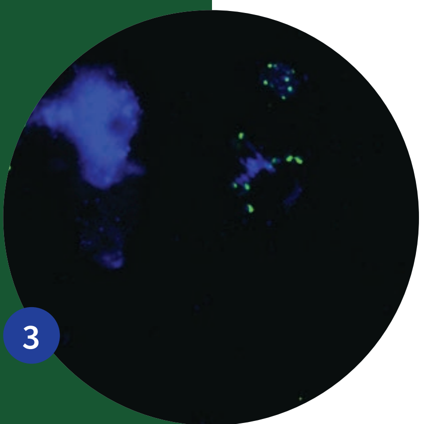




3

Genome-wide identification of disease resistance genes in the Brassicaceae and characterisation of their DNA methylation status in Brassica napus

Project team: Professor Jacqueline Batley (leader; jacqueline.batley@uwa.edu.au), Professor David Edwards, Dr Philipp Bayer, Ms Soodeh Tirnaz, Ms Clementine Merce

Collaborating organisations: UWA; GRDC

The Brassicaceae family consists of more than 3000 species, including important *Brassica* crop species, such as *B. napus* (canola), *B. rapa* (e.g turnip and bok choy) and *B. oleracea* (e.g kale, broccoli and cauliflower), along with the model plants *Arabidopsis thaliana*, *A. halleri* and *Lepidium meyenii*. Blackleg disease, caused by the fungus *Leptosphaeria maculans*, imposes a significant yield loss of crop species from the Brassicaceae annually worldwide. One approach of decreasing yield losses is the identification and characterization of resistance gene analogs (RGAs) and subsequent use of them in breeding. RGAs, such as nucleotide-binding site-leucine-rich repeat (NLR), receptor like kinases (RLK) and receptor like proteins (RLP) genes, play important roles in resistance against pathogens. The resistance response relies on the expression regulation of stress-responsive genes, including RGAs. Epigenetic marks, such as DNA methylation, are used by plants to regulate gene expression. Pathogen-induced DNA methylation modification is an important regulatory mechanism in a plants defence system. In this regard, the two main aims of this study are:

1. Identification and characterization of RGAs in the Brassicaceae family (total of 32 genomes available), and
2. Investigation of RGA methylation patterns in susceptible and resistant cultivars of *B. napus* in response to *L. maculans*.

This study establishes a valuable resource for candidate RGAs, which will facilitate identification and characterization of functional resistance genes in the Brassicaceae family. In addition, this study assists with understanding the role of DNA methylation in plant defence against disease and ultimately helps breeders to optimise the breeding programmes for enhancing resistance against blackleg disease.

To broaden our spectrum on this project and building international collaboration, Ms Soodeh Tirnaz presented the project during visits with Dr. Isabelle Fudal and her team at the National Institute for Agricultural Research (INRA), France, and with the genomics group led by Professor Michele Morgante in Istituto di Genomica Applicata, Udine, Italy.

This research is supported by UWA and GRDC.

1: PhD Candidate Soodeh Tirnaz aims to identify resistance genes analogs within the Brassicaceae family and investigate a novel aspect of plant pathogen interaction.

Identification of candidate Blackleg resistance genes in *Brassica napus* and a candidate avirulence gene in *Leptosphaeria maculans* in the *B. napus* – *L. maculans* pathosystem

Project team: Professor Jacqueline Batley[1] (leader; jacqueline.batley@uwa.edu.au), Professor Martin Barbetti[1], Professor Dave Edwards[1], Dr Thierry Rouxel[2], Dr Marie-Hélène Balesdent[2], Ms Ting Xiang Neik[1], Ms Nur Shuhadah Mohd Saad[1], Ms Bénédicte Ollivier[2], Dr Philipp Bayer[1], Ms Anita Severn-Ellis[1], Dr Aneeta Pradhan[1], Dr Chon-Kit Kenneth Chan[1], Mr Armin Scheben[1], Mr Yuxuan Yuan[1], Ms Yueqi Zhang[1]

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

Canola (*Brassica napus* L.) is a valuable crop mainly sourced for its oil. This crop is heavily infected by the fungal pathogen *Leptosphaeria maculans*, causing blackleg disease. The worldwide economic loss of the *B. napus* crop due to blackleg infection is more than $900 million per growing season. To overcome blackleg disease, breeding resistant *B. napus* varieties is imperative to ensure sustainability. Only two (Rlm2 and LepR3) of the fifteen major resistance genes to blackleg have been cloned, thus far. This project aims to identify the race specific qualitative resistance (R) gene in *B. napus* and the disease-causing effector (AvrLm) gene in *L. maculans*, to help improve our understanding of the complex *Brassica-L. maculans* pathosystem.

The plant and fungal materials were sourced from a short-term research project conducted at the French National Institute for Agricultural Research (INRA) in 2017 as well as from UWA, Perth. Candidate genes for AvrLmS Rlm4 and Rlm7 have now been identified, and nine candidates for Rlm1 have been characterised, using next-generation sequencing methods. Gene validation is currently in progress and the results are expected to be published in 2019.

This research is supported by Underwood PhD Scholarship 2018, SIRF, UWA International Living Allowance Scholarship, UWA Convocation Postgraduate Research Travel Award 2017, UWA International Student Research Training Program Stipend, RTP and UWA Safety-Net Top-Up Scholarship.

2: Cooper (Rlm1) cultivar exhibited a resistance response against infection by isolate UWAP16 (also in the blue circles), while Westar (no Rlm1) exhibited large lesions around the infection point, 11 days after infection.

Identification of novel resistance genes towards *Leptosphaeria maculans* in wild Brassicaceae species

Project team: Professor Jacqueline Batley[1] (leader; jacqueline.batley@uwa.edu.au), Professor Guijun Yan[1], Professor Dave Edwards[1], Dr Annaliese Mason[2], Ms Fangning Zhang[1], Dr Philipp Bayer[1], Ms Anita Severn-Ellis[1], Dr Aneeta Pradhan[1]

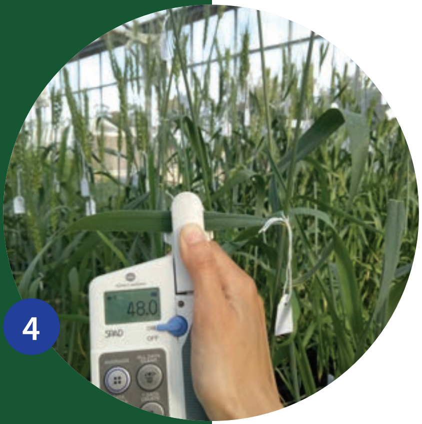
Collaborating organisations: [1]UWA; [2]Department of Breeding, Justus Liebig University of Giessen, Germany

Canola (*Brassica napus* L.) is an economically important crop in Australia, however, yield is severely affected by the fungal disease blackleg caused by *Leptosphaeria maculans*. The breeding of cultivars with stable resistance is the most efficient method to overcome the disease. Some wild species from the Brassicaceae family show high resistance against blackleg. This project looks at the response of some wild species against 10 isolates of *L. maculans* and aims to introduce the resistance into susceptible *B. napus* cultivars through interspecific and intergeneric crossing.

Using the ovary and ovule rescue, the F1 hybrids of three wide crossing combination were successfully acquired in 2018. The flower buds were collected and cytogenetic work of the hybrids was conducted using genomic *in situ* hybridization (GISH) to analyse the chromosome behaviour in meiotic stage. The hybrid status and genome composition of hybrids was confirmed using fluorescent labels. The crossover and overlapping of chromosomes from different genomes show the possibility of resistant genes introgression. Analysis of SNP markers confirmed the species of plant materials acquired from the Australian Grains Genebank and revealed the chromosome regions containing the *R* genes in wild Brassicaceae species. Both cytogenetic laboratory work and SNP data analysis were carried out in the Department of Plant Breeding, University of Giessen Germany, with the support of a Mike Carroll Travelling Fellowship and Convocation Travel Award.

This research is supported by UWA Scholarship for International Research Fees (SIRF China), Ad hoc Top Up scholarship, Mike Carroll Travelling Fellowship 2018, and UWA Convocation Postgraduate Research Travel Award 2018.

3: GISH labelling of meiotic (metaphase I) chromosome spreads unbalanced in three-genome hybrids between B. napus and Raphsnus sativus. Chromosomes painted green are from R genome and chromosome painted blue are from AC genomes.



4

Characterising the role of *Brassica napus* genomic structural variation (presence/absence variation and copy number variation) in disease resistance

Project team: Professor Jacqueline Batley (leader; jacqueline.batley@uwa.edu.au), Professor Dave Edwards, Professor Martin Barbetti, Mr Aria Dolatabadian, Dr Philipp Bayer, Mr Yuxuan Yuan, Dr Bhavna Hurgobin

Canola (*Brassica napus* L.) is an economically important oilseed crop worldwide. A number of diseases can affect canola yield. Blackleg, caused by the fungus *Leptosphaeria maculans*, is the most devastating fungal pathogen of canola in Australia. One of the most effective strategies to overcome this disease is to develop resistant cultivars. The first step in this effort is to identify and characterize disease resistance genes (R genes) to harness them for genetic improvement of varieties. Plant genomic variation ranges from single nucleotide polymorphisms (SNPs) to large-scale structural variations including presence/absence variation (PAV) and copy number variation (CNV). These variations often encompass genes and have phenotypic effects.

This project aims to characterise the role of genomic structural variation including PAV and CNV in the role of disease resistance in canola. To this end, we performed a genome-wide CNV and PAV analysis using whole genome sequencing data. A total of 1,749 resistance gene analogs (RGAs) were identified in the *B. napus* pangenome, of which 43% showed PAV between the different lines. These results were presented at the Brassica 2018 Conference held in St Malo, France. In addition, CNV analyses detected 563 R genes, showing a total of 1,137 CNV events across 8 varieties. Collectively, these findings suggest that PAV and CNV are important sources of genomic variation playing a key role in disease resistance in *B. napus*. These results provide a useful genomic resource to facilitate further research on phenotypic variation and breeding and advance our understanding of the mechanisms underlying resistance in *B. napus*.

As part of this project, Mr Aria Dolatabadian travelled to Poland in November 2018 to meet Professor Malgorzata Jedryczka (The Institute of Plant Genetics, Polish Academy of Sciences, Poznan, Poland) who is an expert in aerobiology and aeromycology. The main purpose of his travel was to gain experience in aerobiology and molecular detection of fungal spores in the air using the SPEC system (a system of disease forecasting in canola that allows for monitoring of the presence and concentration of spores in air samples) and spore trapping equipment.

This research is supported by SIRF, UWA International Living Allowance Scholarship, and UWA Convocation Postgraduate Research Travel Award.

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

Project team: Professor Guijun Yan (leader; guijun.yan@uwa.edu.au); Dr Hui Liu (leader; hui.liu@uwa.edu.au)

Wheat is a staple food that is cultivated all over the world. It is important not only for domestic consumption, but also for the export economy of Australia. However, wheat production in Australia is seriously affected by frequent heatwaves causing the loss of hundreds of millions of dollars every year. Wheat is highly susceptible to heat stress at the reproductive stage and high temperatures may lead to a reduction of wheat yield and grain quality. Due to the convenience of screening, evaluating wheat germplasm for their performance under heat stress at the seedling stage is an option.

As the relationship between seedling stage heat tolerance (HT) and reproductive stage performance is unknown, this research aims to understand the genetic mechanisms of HT in wheat through a comparative study of plant responses to heat at both early (seedling) stage and adult (reproductive) stage. Another aim of the study is to develop a new, rapid method of screening and selecting superior HT wheat varieties. Some identified signature molecules can be directly used as, or developed into, functional markers to improve the efficiency of practical wheat breeding for HT.

Some highlights of 2018 include:

Recombinant inbred line (RIL), near-isogenic line (NIL) pairs and some selected cultivars were screened for HT performance at seedling and reproductive stages.

Seedling stage: Phenotyping screening including shoot length (SL), root length (RL) and whole length (WL) for Synthetic/Opata population were completed using a newly developed laboratory-based system. After genotype-phenotype association analysis, Opata was confirmed to be the HT contributing parent and five QTLs were identified conferring HT at seedling stage. These QTLs will be validated using cross populations of Opata with three selected genotypes which were Cascades, Halberd and Yitpi. The seeds of F1 (the first generation) has been obtained and F3 or F4 will be used for validation.

Reproductive stage: Different genotypes were grown in a natural-light glasshouse, including 16 heat tolerant (HT) and 16 heat susceptible (HS) cultivars which were previously identified during their seedling stage and 13 pairs of HT NILs (F8, which were developed previously) with their parents. Each genotype has six duplications.

The original anthesis date was recorded and the heat treatment started ten days later. Three duplicates for each line were put into a 37/27˚C (day/night) phytotron for three days with a 14-hour photoperiod per day. These were then returned to a non-stress condition. The chlorophyll contents of flag leaf on main stems were measured by SPAD chlorophyll meter. The measurement was repeated for both non-stressed and heat-stressed plants at 10 days and 13 days after anthesis.

The measurement of SPAD has finished and grain weight and grain number measurements are underway. After all the trait data are obtained, the variation among various genotypes can be analysed.

This research is supported by AusIndustry and Chengdu Institute of Biology, CAS, China.

4: Adult stage phenotyping measurement.

Characterisation of drought tolerant wheat at the seedling and grain-filling stages

Project team: Professor Guijun Yan (leader; guijun.yan@uwa.edu.au), Ms Pratima Gurung, Adjunct Professor Neil C. Turner, Dr Hui Liu, Visiting Professor Yongzhong Luo, Mr Md Sultan Mia

Collaborating organisations: UWA; Gansu Agricultural University, Lanzhou, China

This study focuses on drought stress tolerance in wheat genotypes at two important stages: the seedling stage and the grain-filling stage. A total of ten genotypes are being studied. Nine were chosen based on an initial screening for drought tolerance at the seedling stage (Ayalew et al. 2015) and the tenth genotype is a current variety widely grown in Western Australia. The project is divided into two separate experiments.

In the first experiment, water was withheld during (i) the seedling stage and (ii) the grain-filling stage. The plants stressed during the seedling stage were grown in soil in coir forestry tubes (through which the roots can grow when transplanted into larger pots) and later transplanted into cylindrical pots (420 mm height and 85 mm in diameter), whereas the plants stressed during the grain-filling stage were sown directly into the pots. A preliminary experiment determined the amount of soil per coir pot to ensure a similar stress level to that in the plants at the grain-filling stage. In the glasshouse, the drought stress at the seedling stage was induced in ten-day-old plants by not watering them for seven days. In the grain-filling stage, the watering was stopped for 10 days after the genotypes reached 50% anthesis. The rate of leaf photosynthesis, leaf water potential, soil water content and leaf chlorophyll content were measured in the well-watered and water-stressed plants during the soil drying cycle. After the stress period, the plants were rewatered until maturity, when the plants were harvested for yield and biomass.

The aim of the experiment is to compare the genotypic responses of wheat to water deficit at the seedling stage and the grain-filling stage in wheat. The research question is whether selection for drought resistance (identified by root length and early biomass accumulation) correlates with differences in grain yield at maturity and whether genotypes that differ in drought resistance imposed at the seedling stage have the same resistance to drought imposed during grain filling.

In the second experiment, the same ten genotypes will be grown at the seedling stage in a constant-temperature room in either (1) a hydroponic system (Ayalew et al. 2015) or (2) the same coir-pot soil system as in Experiment 1. Seeds will first be germinated in Petri dishes and then transferred to the hydroponic or soil system. In the hydroponic system plants will be grown in water for the first seven days and then in (i) half-strength Hoagland's solution as a control, and (ii) in a combination of half-strength Hoagland's solution and polyethylene glycol (PEG6000) to impose a simulated water stress treatment for seven days. In the soil system the plants, after seven days of germination, will be stressed, by not watering them, for the following seven days. Photosynthesis, leaf water potential and leaf chlorophyll content will be measured during the seven-day stress period, after which root length and shoot length will be recorded.

The aim of this second experiment is to understand if wheat seedlings show the same ranking and/or growth when PEG is used to stress the plants instead of drying them in soil. In conjunction with Experiment 1, it will assess whether either technique for stressing the plants at the seedling stage is useful for identifying drought resistance in wheat imposed during the reproductive phase.

Reference: Ayalew H, Ma X, Yan G (2015) Screening wheat (*Triticum spp.*) genotypes for root length under contrasting water regimes: potential sources of variability for drought resistance breeding. *Journal of Agronomy and Crop Science* 201, 189-194.

This research is supported by CDIIS; and Gansu Agricultural University, Lanzhou, China.

5: Ten wheat genotypes growing in glasshouse facility, UWA.

6

Genetic analysis of seed dormancy for pre-harvest sprouting resistance in wheat

Project team: Professor Guijun Yan (leader; guijun.yan@uwa.edu.au), Miss Xingyi Wang, Dr Hui Liu, Hackett Professor Kadambot Siddique

Pre-harvest sprouting (PHS) can cause severe damage to the quality and production of wheat, which is the major cultivated and exported grain crop in Australia. PHS refers to the phenomenon that the un-harvested wheat grains germinate or sprout on the plant in the field when they encounter rain or air-humidity close to saturation. PHS is considered as a lack of seed dormancy, which is a quantitative trait regulated by several genes and affected by environmental factors.

Some important quantitative trait loci (QTL) for PHS resistance have been consistently identified on the chromosome 3A, 4A and 4B. To identify the specific genes for PHS resistance, near-isogenic lines (NILs) were developed using the closest makers to the QTL on 3A, 4A and 4B. An embryo-culture based, fast generation system was used to shorten the developing period.

In 2018, SNP array analysis was conducted on the confirmed 5 pairs of NILs developed for PHS resistance genes on chromosome 4B, to identify single nucleotide polymorphisms (SNPs) for marker development study. A total of 31,807 SNPs were identified on the whole 21 chromosomes; 990 of which were located on chromosome 4B. Comparing the 990 SNPs genotypes in the isolines, eight SNPs were conformed to the expectations showing only AA in the resistant isolines group and BB in the susceptible isolines group. Locating the eight SNPs on the latest Chinese Spring reference genome, five of them were annotated as protein coding genes. The previous research showed that three of five functional genes were involved in dormancy or germination in model species.

To identify the putative candidate genes responsible for PHS resistance on the long arm of chromosome 3A, transcriptomic analysis was conducted on two confirmed NIL pairs. Qualified RNA samples were sent to the sequencing company (BGI), where 150-bp paired end sequencing libraries were prepared and sequenced using HiSeq X Ten (Illumina, San Diego, USA) according to standard protocols. A total of 625 Gb high quality reads were generated for a total of 36 samples (4 genotypes x 3 time points x 3 replicates) after quality control. The total reads were mapped and annotated on the wheat reference genome. A total of 793 differentially expressed genes (DEGs) were commonly detected in the two tested NIL pairs, of which, 38 DEGs were located on the long arm of chromosome 3A. GO and pathway enrichment analysis indicated 12 candidate genes involved in regulating gibberellic acid (GA), among which, nine were confirmed by qRT-PCR showing the same tendency with RNA-seq.

This research is supported by The UWA School of Agriculture and Environment; Yipti Foundation: Research Awards and Grants-in-Aid; and Global Innovation Linkage program (GIL53853) by CDIIS.

6: Spikes and plants of a pair of near isogenic lines (NIL_PHSR4BL_5R on the left and NIL_PHSR4BL_5S on the right) showing significant differences in spike sprouting at day seven.

7

Genetic and genomic analysis of herbicide tolerance in bread wheat (*Triticum aestivum*. L.)

Project team: Ms Roopali Bhoite, Prof Guijun Yan (leader; guijun.yan@uwa.edu.au), Dr Ping Si, Hackett Prof Kadambot Siddique

Wheat (*Triticum aestivum* L.) is one of the major global cereal grains in terms of production and area coverage (FAO 2018) and is Australia's largest grain crop contributing between 8% and 15% of world trade. However, Western Australia (WA) has the highest reported occurrence of herbicide-resistant weeds in Australia, which is the key agronomic issue for WA farmers. Controlling weeds is one of the toughest challenges farmers face. There are approximately 30,000 weeds that compete with crops. High weed pressure negatively affects tillering in seedling wheat and thereby reduces crop yield up to 50%. Herbicide tolerance in wheat crops is an important trait that allows effective weed management and maximize wheat yield in dry land farming.

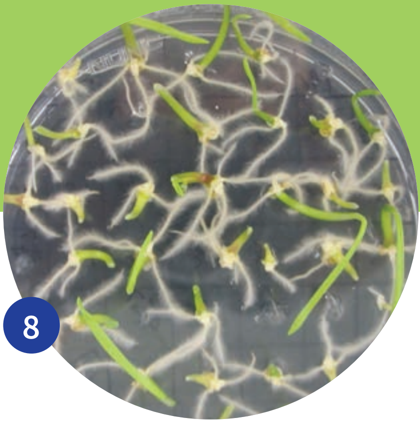
Genetic variation of herbicide tolerance was investigated in 946 wheat diversity panels representing six continents. The most contrasting genotypes for metribuzin tolerance have been identified (https://doi.org/10.1071/CP17017). We have mapped QTLs and identified genomic regions responsible for metribuzin tolerance (https://rdcu.be/bbLTp). Genetic studies of gene effects and SNP discovery in diverse gene pools using 90K iSelect SNP genotyping assay followed by genomic regions governing metribuzin tolerance have been investigated. A detailed dose-response experiment with pre-emergent application was conducted in the glasshouse for the top six tolerant and four susceptible genotypes, to determine the best contrasting genotypes. The metribuzin effects were further validated in field conditions during the winter of 2018 at Shenton Park field station, Perth, Western Australia (coordinates: 31.9480˚S, 115.7955˚E). Herbicide rates were chosen to span the estimated LD50 confidence range (0, 200, 400 and 800 g a.i. ha–1) for all genotypes. Metribuzin was sprayed using a hand-held liquid herbicide applicator immediately after sowing. At 21 days after treatment (DAT), wheat seedlings in different herbicide treatments were visually scored for senescence and survival rate.

Next generation transcriptome sequencing of the most diverse genotypes was performed using the Novaseq RNA-Seq platform according to the manufacturer's instructions (Illumina, San Diego, CA). The key genes/functional markers and metabolic detoxification enzymes/proteins identified will have an immediate application in marker-assisted selection for herbicide-tolerance breeding. PSII efficiency in elite germplasm may be enhanced to a larger fold during metribuzin stress by introgressing identified genes involved in herbicide tolerance in a variety improvement programme.

This will be a more effective strategy to control weeds without compromising wheat productivity in dry-land farming of Australia and worldwide. This research, using transcriptome studies of susceptible and tolerant wheat varieties to decipher genes and key pathways involved in herbicide resistance, is a world first.

This research is supported by RTP and the Yitpi Foundation Research Awards and Grants-in-Aid.

7: PhD student Roopali Bhoite applying Metribuzin at the UWA Shenton Park Field Station, in order to measure Metribuzin response in two contrasting wheat genotypes: Chuan Mai 25 (herbicide tolerant) and Ritchie (herbicide susceptible).



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

Project team: Professor Guijun Yan (leader; guijun.yan@uwa.edu.au), Miss Guannan Liu (MSc), Dr Hui Liu, Dr Dan Mullan

Wheat (*Triticum aestivum* L.) is the most important crop grown in Australia. The large and complex genome of wheat makes it difficult for identification of functional markers for marker assisted breeding. Genome sequencing is a rapidly advancing area, which has a great potential in speeding up discovery of molecular markers or functional genes for molecular breeding.

This PhD research project is to apply single nucleotide polymorphism (SNP) array and genotype by sequencing (GBS) technologies to study the genetic variations of representative wheat lines including domesticated cultivars and cross population progenies such as near isogenic lines (NILs) and recombinant inbred lines (RILs). Several important agronomic traits including pre-harvest sprouting (PHS), drought and herbicide tolerance will be investigated. Specifically, genotypes with extreme (best or worst) performances of the traits will be genotyped using array and sequencing technologies and genes or quantitative trait loci of interest will be scrutinized to identify the major polymorphisms between the extreme genotypes. Genes and gene networks for specific trait development will be studied. DNA markers tightly linked to genes of interest will be developed and then validated on a wide range of wheat germplasm before implementation in breeding programs. It is expected that a number of functional markers for genes of breeding interest will be developed through this study, which can be cost-effectively applied to marker-assisted selection (MAS) in wheat breeding. The overall aim is to develop an efficient system for the identification of molecular markers for MAS in wheat, which has a large polyploid genome.

There are three major highlights in the 2018 research. Firstly, DNA extraction has finished for the PHS tolerance experiment and the drought tolerance experiment. Based on the literature and the materials phenotyped in our lab, 17 pairs of PHS tolerant/susceptible NILs and 9 pairs of drought tolerant/ susceptible NILs were selected. All of them were grown in a glasshouse condition. Leaves at seedling stage were selected for DNA collection, with each sample in duplicate. The quality and concentration of the DNA were tested by NanoDrop and Qubit. Secondly, detection of molecular markers for the PHS tolerance experiment and the drought tolerance experiment has been partially completed. A genotyping test was undertaken using Illumina SNP chip. Clustering and genotype calling for hexaploid wheat was done using GenomeStudio 2.0 software. A total of 81,587 SNPs were analysed and clustered at this stage. Thirdly, an RIL population has been developed for herbicide tolerance. F8 RILs for herbicide tolerance/ susceptibility are the desirable material in this study. These RILs were derived from the cross between Chunmai 25 (metribuzin tolerance) and Ritchie (metribuzin susceptible) and were grown in a controlled temperature room using both embryo culture and traditional culture to shorten the cultivation time.

This research is supported by RTP and the Global Innovation Linkage Projects.

8: Embryo culture of herbicide tolerant/ susceptible RILs for fast generation.

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Increasing wheat yield by genomic sequencing and germplasm exchange

Project team: Professor Guijun Yan (leader; guijun.yan@uwa.edu.au), Professor Dave Edwards, Professor Jacqui Batley, Dr Hui Liu, Dr Dan Mullan, Professor Aimin Zhang, Professor Yong Zhang, Professor Zhanyuan Lu, Professor Yong Wang, Professor Haibo Wang, Dr Shancen Zhao

Collaborating organisations: UWA; InterGrain Pty Ltd; CAS; CAAS; Inner Mongolia Academy of Agriculture and Animal Husbandry Sciences; Gansu Academy of Agricultural Sciences; Beijing Genomics Institute

This project uses genome sequencing technology to investigate diverse germplasm resources in Australia and China, and to accelerate the breeding of improved wheat varieties adapted for high productivity and good quality in target environments.

Genotyping of 120 Australian cultivars and 128 Chinese cultivars has been completed using 90k SNP assay and genotyping by sequencing technologies. 30 Australian and 30 Chinese cultivars have been selected and exchanged among the participant organizations. Crosses with local elite lines have been done and their resulting populations are being advanced to pure lines using a fast generation cycling system. A 15k SNP chip assay and a KASP marker assay have been developed at the partner organizations and are now at the validation stage.

As adaptabilities such as drought tolerance and heat tolerance are also major factors influencing wheat yield in the rain-fed environment, these traits have also been scrutinized for their genetic variation, heritability and regulation. Near-isogenic lines targeting major genomic region for drought tolerance and heat tolerance have been developed using a fast generation cycling system. Genomic and transcriptomic information of tolerant and susceptible lines were compared and tolerance mechanisms were investigated. Major publications on wheat adaptability, quality and yield include:

- Ohyemaobi et al, 2018, Identification and validation of a major chromosome region for high grain number per spike under meiotic stage water stress in wheat (*Triticum aestivum* L.). *PLoS One*. 13(3): e0194075.
- Wang et al, 2018. Development of near-isogenic lines targeting a major QTL on 3AL for pre-harvest sprouting resistance in bread wheat. *Crop & Pasture Science*, doi: 10.1071/CP17423
- Ayalew et al, 2018. Genome-Wide Association Mapping of Major Root Length QTLs Under PEG Induced Water Stress in Wheat. *Frontiers in Plant Science* 9: 1759
- Ayalew et al, 2018. Identification of Early Vigor QTLs and QTL by Environment Interactions in Wheat (*Triticum aestivum* L.). *Plant Molecular Biology Reporter* 36:399–405

This research is supported by CDIIS.

9: Hybridized wheat 90k SNP chips that are ready to be washed up.

Effect of the TaMATE1B gene on the above and below-ground growth of wheat on an acid soil with high Al^{3+}

Project team: Hackett Professor Kadambot Siddique[1] (leader; kadambot.siddique@uwa.edu.au), Dr Vijay Pooniya[1,2] (Endeavour Research Fellow), Adjunct Professor Jairo Palta[3], Dr Yinglong Chen[1], Dr Emmanuel Delhaize[3]

Collaborating organisations: [1]UWA; [2]Indian Agricultural Resrch Institute (IARI), New Delhi; [3]CSIRO Agriculture & Food, Perth and Canberra

Durum wheat (tetraploid AABB, *Triticum turgidum*) is a species that grows poorly on acid soils due to its sensitivity of Al^{3+}. By contrast, the growth of bread wheat (hexaploid AABBDD, Triticum aestivum) on acid soils with high Al^{3+} has a large variation, mainly because of a major gene (TaALMT1) located on chromosome 4D as well as other minor effect genes such as TaMATE1B. Since the genotypic variation of durum wheat for acid soils with high Al^{3+} is very narrow, the introgression of genes from bread wheat has been suggested as an option for improving the tolerance of durum wheat to acid soils with high Al^{3+}. Dr Emmanuel Delhaize from CSIRO Agriculture & Food, Canberra has introgressed the TaALMT1 (malate gene), and TaMATE1B (citrate gene) genes into the durum wheat cultivar Jandaroi. The lines Jandaroi-Null; Jandaroi–TaALMT1 and Jandaroi-TaMATE1B have only been preliminary tested in a small pot and short-term soil experiment, where the most effective gene for tolerance to acid soils with high Al^{3+} was the line Jandaroi-TaMATE1B. This is surprising because it is the opposite in bread wheat, the source of both genes. The line with the two genes together (Jandaroi-TaALMT1-TaMATE1B) was also preliminary tested in plants grown in small pots for a week and the tolerance to acid soils with high Al^{3+} was not better than in Jandaroi-TaMATE1B.

This study aimed to evaluate the effects of the TaMATE1B gene on the shoot and root growth, yield and grain yield components of durum wheat when grown on an acid soil with high Al^{3+}.

The study objectives were to measure the shoot (leaf area, tiller number and biomass) and root traits (root length, root biomass), and phenology of durum wheat lines with and without the TaMATE1B gene.

This study accessed the impact of the TaMATE1B gene on the shoot and root traits in durum wheat when grown under subsoil acidity conditions with high Al^{3+}. The association between root characteristics and the TaMATE1B gene was observed and revealed the significant positive effect in the Al^{3+} tolerance mechanism. Durum wheat cultivar 'Jandaroi–TaMATE1B' had greater root length, more root biomass and root length density than 'Jandaroi–null'. Also, 'Jandaroi–TaMATE1B' took longer to reach anthesis and had larger root systems than 'Jandaroi–null' that reached anthesis earlier. Further studies are in progress to asses yield and water use of the above lines under terminal drought conditions in acid soils.

This research is supported by Department of Education and Training, Government of Australia as Endeavour Research Fellowship, and IOA.

10: Prof Kadambot Siddique, Dr Vijay Pooniya and Adjunct Prof Jairo Palta inspect the rhizobox experiment in the UWA glasshouses.

Understanding the role of root morphology, arbuscular mycorrhizal fungi and carboxylate exudation in phosphorus acquisition at contrasting soil P levels in chickpea

Project team: Hackett Professor Kadambot Siddique (leader; kadambot.siddique@uwa.edu.au), Dr Jiayin Pang, Professor Hans Lambers, Associate Professor Megan Ryan, Mr Zhihui Wen, Dr Yifei Liu, Mr Guillaume Tueux, Dr Sasha Jenkins, Dr Bede Mickan

Collaborating organisations: [1]UWA; China Agricultural University, China; Shenyang Agricultural University, China; Purpan Agronomy Engineering School, France; Richgro, Australia

Low availability of phosphorus (P) is considered a major constraint to crop production worldwide. While the problem of P deficiency is currently mitigated by application of high rates of P fertiliser, this practice is inherently inefficient due to chemical immobilisation of P and agricultural runoff. Therefore, breeding crops for improved P-use efficiency, for instance, an improved production of yield per unit of added P fertiliser, is arguably the best long-term environmentally sustainable strategy.

Chickpea has become the second most important grain legume (pulse) globally, and it is the largest pulse crop in Australia, currently grown on >0.5 million ha (FAOSTAT 2014). In our previous screening for P-use efficiency under low P conditions, using a unique chickpea reference set consisting of 270 genotypes from 29 countries with diverse genetic background developed by the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) in India, we found large genotypic variation in P-acquisition and P-use efficiency. The aims of the project were to investigate the belowground root functional traits associated with P acquisition under different P sources and P levels, including root morphology, exudation of carboxylates and colonisation by arbuscular mycorrhizal fungi.

In 2018, a glasshouse study was conducted involving two chickpea genotypes (one with high amounts of carboxylates per gram root DW and the other with low amounts of carboxylates per gram root DW), grown under two P sources (FePO4, insoluble P source, or KH2PO4, soluble P source) at six different P levels. Under KH2PO4, large responses to different P levels were found in shoot and root growth, root mass ratio, nodulation, shoot P concentration, leaf N:P ratio, total root length, specific root length, colonisation by arbuscular mycorrhizal fungi, amounts of carboxylates in rhizosheath. While under FePO4, chickpea had poor nodulation, and little variation in shoot and root growth among different P levels, which was much lower than those under KH2PO4. Further analysis is under way to investigate the difference in the contribution of belowground traits to P acquisition under different P levels, including the diversity and function of microbial community in rhizosheath soil.

This research is supported by IOA.

11: A group of researchers meeting in the glasshouse to look at the growth of chickpea under different phosphorus treatments.

Multiple root functional traits in response to different P supply in 20 chickpea genotypes with contrasting amount of carboxylates in rhizosheath

Project team: Hackett Professor Kadambot Siddique (leader; kadambot.siddique@uwa.edu.au), Mr Zhihui Wen, Dr Jiayin Pang, Professor Hans Lambers, Associate Professor Megan Ryan, Dr Yifei Liu, Mr Guillaume Tueux, Dr Sasha Jenkins, Dr Bede Mickan

Collaborating organisations: [1]UWA; China Agricultural University, China; Shenyang Agricultural University, China; Purpan Agronomy Engineering School, France; Richgro, Australia

Phosphorus (P), as one of the most growth-limiting macronutrients, needs to be taken up from the soil by plant roots. However, only 10–25% of applied fertilizer P is taken up by crops in the first growing season, due to the easy adsorption and fixation of P in soil. A global problem of P imbalance between input and export, and the low P-use efficiency can lead to not only a waste of resource, but also a series of environmental impacts. Plants have evolved various strategies to acquire P from soils, those include i) expanding soil-root contact by increasing the root surface area; ii) the release of P-mobilizing exudates (for example, carboxylates and protons) into rhizosphere to mining the sparingly soluble inorganic and organic P; iii) enhance the symbioses with mycorrhizal fungi to access P from the labile inorganic soil P pool beyond root P-depletion zones. Thus, how to improve P-use efficiency of crops by maximizing root/rhizosphere efficiency has become an urgent and critical issue for sustainable agricultural development.

Chickpea (*Cicer arietinum* L.) is the second most important grain legume in the world, and it is also the largest leguminous crop in Australia. Based on our previous study, chickpea genotypes with diverse genetic backgrounds exhibited a large genotypic variation in their root morphology and the amounts of rhizosheath carboxylates per root dry weight under low-P conditions. However, the genotypic variation in mycorrhizal colonization among chickpea genotypes remain little understood.

The aims of the project were to investigate i) the response of multiple root functional traits associated with P acquisition under different P treatments; ii) how do chickpea plants coordinate their diverse root functional traits (for instance, root morphology, root exudates and mycorrhizal traits) to respond to varying soil P availability?

In 2018, a glasshouse study was conducted using 20 chickpea genotypes (ten with high amounts of rhizosheath carboxylates and another ten with low amounts of rhizosheath carboxylates), grown under three P treatments (10 mg P kg-1 as FePO4, water-insoluble P, 10 or 50 mg P kg-1 as KH2PO4, water-soluble P source). Substantial genotypic variation in root functional traits associated with P-acquisition was found. Compared with the genotypes with low rhizosheath carboxylates, genotypes with high rhizosheath carboxylates have consistently lower root mass ratio, root tissue density, and mean root diameter, while having higher specific root length and colonization by mycorrhizal fungi.

Most chickpea genotypes showed large plasticity in rhizosheath pH and carboxylates, and colonization by mycorrhizal fungi to soil P availability, but a poor plasticity in root morphology-related traits. Such knowledge has provided important implications for the breeding selection of belowground root traits associated with enhanced P acquisition and improved chickpea production.

This research is supported by IOA.

12: Twenty chickpea genotypes with contrasting amounts of rhizosheath carboxylates grown in the glasshouse.

Genetics of wild germplasm gene-pool expansion and integrated aSSD approach to enhance adaptive potential of chickpea

Project team: Dr Janine Croser (leader; janine.croser@uwa.edu.au), Dr Maria Pazos-Navarro, Ms Simone Wells

Collaborating organisations: [1]UWA; Curtin University; CSIRO; Australian Grains Genebank; Plant Breeding Australia Chickpea Improvement Program; Chickpea Innovation Lab, UC Davis & partners within the chickpea consortium

Cultivated chickpea (*Cicer arietinum* L.) is known to have low genetic diversity. GRDC investment led to the collection of hundreds of new wild *Cicer* accessions, particularly of *Cicer reticulatum* (the wild progenitor of chickpea) and *Cicer echinospermum* (a closely related annual species). This new material represented a unique opportunity to evaluate and introduce desirable traits into domestic chickpea. A world set of wild *Cicer* nested association marker (NAM) parents was identified and has formed the basis of introgression efforts to create new genetic resources in the five partner countries (US, Canada, Ethiopia, Turkey and Australia).

The UWA node's aim was to develop a controlled environment, rapid generation cycling platform to accelerate the integration of desirable traits from the wild into the domestic chickpea.

At UWA, we have been investigating the role of light, photoperiod and temperature on the induction of early flowering and seed development in the wild material. Our results have led to the establishment of a Rapid Gene Introgression (RGI) platform enabling the turnover of up to five generations per year following an interspecific cross between domestic and wild *Cicer.*

In 2018, selected F1 hybrid material were grown and cloned to produce high F2 seed numbers - up to 2000 for domestic x *C. echinospermum* crosses with high sterility. Using the RGI platform, two interspecific RIL populations have been generated from crosses undertaken with NAM parents at UWA.

The Rapid Gene Introgression platform developed at UWA represents a successful mechanism to rapidly harness traits from wild germplasm and has the potential to be adapted to wild relatives from other species including lentil.

This research is supported by GRDC.

13: Hybrid domestic x wild Cicer populations grown under RGI conditions. Photo: Dr Maria Pazos-Navarro.

Phosphorus acquisition and facilitation under grazing

Project team: Professor Hans Lambers[1], Weiping Zhang, Yingchai Yu, Shubing Yu, Long Li (leader; lilong@cau.edu.cn)

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

Long-term overgrazing tends to cause soil phosphorus (P) deficiency in grasslands. Grazing induces shifts in species composition, yet the root traits associated with P acquisition involved in these shifts remain unknown. Species vary in their P-acquisition strategies, and we hypothesize that species which acquire P more efficiently are better adapted to overgrazing and facilitate neighbour species via rhizosphere processes on P-impoverished soils.

We measured relative biomass, root physiological activities (e.g. rhizosphere acid phosphatase activity, and leaf manganese concentration ([Mn]) as a proxy for carboxylate release) and morphological traits (e.g. specific root length) of six common species in a field experiment conducted in a typical steppe of Inner Mongolia. Then, we grew species with various abilities to mobilize sorbed P together in a glasshouse experiment with defoliation (to simulate grazing) and P addition; 11 root functional traits related to P acquisition were selected.

The field study highlighted species with finer roots and/or stronger P mobilization that fitted the P-impoverished soils, like *Carex duriuscula* and *Cleistogenes squarrosa*, were better adapted to long-term overgrazing; whereas species with both inefficient morphological and physiological traits (e.g. low specific root length and leaf [Mn]), like *Stipa grandis*, were replaced under grazing.

The results of the glasshouse experiment showed leaf [Mn] was positively correlated with rhizosheath carboxylate concentration on P-deficient soils, but not on P-rich soils. Species neighboured with *Carex korshinskyi* usually had greater leaf [Mn] on P-deficient soils, especially under defoliation, indicating P facilitation via rhizosphere process. The results supported that Poaceae (like *C. squarrosa*) often do not release large amounts of carboxylates, but can be facilitated by its neighbour (like Carex species), which explained the high leaf [Mn] and species dominance of *C. squarrosa* under overgrazing in the field study.

Our study highlights the importance of acknowledging root traits involved in efficient P acquisition for theories on community succession induced by overgrazing. The results also highlight the importance of interspecific P facilitation via rhizosphere process, proposing a new framework to explain species coexistence in P-limited communities.

This research is supported by National Key Basic Research Program of China (Project No: 2014CB138801), and National Natural Science Foundation of China (NSFC) (Project No: 30870406).

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

Project team: Professor Hans Lambers (leader; hans.lambers@uwa.edu.au), Yifei Liu, Jiayin Pang, Qingwen Shi, John Yong, Chunming Bai, Caio Guilherme Pereira

Collaborating organisations: [1]UWA; College of Land and Environment, National Engineering Laboratory for Efficient Utilisation of Soil and Fertiliser Resources, Key Laboratory of Protected Horticulture of Ministry of Education, Shenyang Agricultural University, Shenyang Liaoning 110161, China; Department of Biosystems and Technology, Swedish University of Agricultural Sciences, SLU Alnarp 23053, Sweden; Liaoning Academy of Agricultural Sciences, Shenyang Liaoning 110161, China; Ralph M. Parsons Laboratory for Environmental Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, 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.

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) were investigated.

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, 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*.

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Rhizosphere properties of sweet potato under low phosphorus conditions

Project team: David Minemba (leader; 21559602@student.uwa.edu.au), Associate Professor Megan Ryan[1], Dr Deirdre Gleeson, Professor Erik Veneklaas[1], Dr Arthur Villordon[2]

Collaborating organisations: [1]UWA; [2]Louisana State University AgCentre; Sweet Potato Research Station

Sweet potato is an important staple root crop in many developing countries located in the tropics and warm temperate regions. It grows well in low-input farming systems in highly weathered soils characterised by sub-optimal levels of nutrients including phosphorus (P). Better understanding of how sweet potato grows under low P conditions could be applied in plant selection programs to improve yields. This study investigates the root and shoot characteristics of sweet potato that aid P acquisition and efficient use of P when growing in low P soils.

In 2018, several experiments were undertaken. Several sweet potato cultivars, including some native to Papua New Guinea, were grown under deficient or sufficient P supply. Results showed that sweet potato does not invest its carbon resources into the plant root strategies that are commonly found in crops to assist with P acquisition. Sweet potato instead demonstrated a remarkable ability to maintain a constant low tissue P concentration when P supply is limited. It efficiently converted the P that was accessed from soil into new biomass; it had a high internal P use efficiency (PUE). Variations in PUE among the cultivars suggest the opportunity to select for high PUE genotypes.

Also measured, for the first time, was the exudation rate of organic acids from sweet potato cultivars, this showed that oxalate is the primary organic acid exuded. The rate of exudation was low. Bacterial diversity in the rhizosphere of sweet potato and its relationship to organic anion exudation was also examined. Also of interest was the detection in some treatments of P-solubilising bacteria.

This research is supported by Australia Awards Scholarship and UWA Postgraduate support.

14: David Minemba with a P response glasshouse experiment.

Ecophysiological studies on *Lupinus* species- variation of the P supply does not relate consistently to a Lupine species' ability to tolerate alkaline soil pH

Project team: Professor Hans Lambers (leader; hans.lambers@uwa.edu.au), Omnia Arief, Dr Jiayin Pang, Professor Kamal H Shaltout

Collaborating organisations: UWA; Benha University Egypt; Tanta University Egypt

The relationship between carboxylate release and the ability of plants to access phosphorus at different pH was studied by comparing species with no carboxylate release (*Helianthus annuus*) and carboxylate release (four *Lupinus* species (*L. albus L.* P27334, *L. angustifolius L*. cv Mandelup, *L. luteus L.* cv Pootalong and *L. pilosus* Murr. P27440), respectively.

This research is supported by The Mission sector, the Ministry of Higher education, Egypt.

15: Lupinus pilosus Murr. P27440 at the end of 6 weeks experiment at pH 6 and P level 7.5 mg P kg-1 soil.

Is the pattern of calcium and phosphorus allocation to specific leaf cell types the key reason why different Lupinus species respond differently to calcareous soil?

Project team: Professor Hans Lambers (leader; hans.lambers@uwa.edu.au), Dr Peta Clode, Dr Jon Clements, Wenli Ding

Collaborating organisations: UWA; DPIRD

The calcifuge syndrome is often explained in terms of pH or pH-buffering capacity, and this explanation is satisfactory in many cases. However, for species that produce carboxylate-exuding (cluster) roots, these classic explanations make little sense, because these species would have the capacity to strongly acidify their rhizosphere, and thus mobilise nutrients that are poorly available at a high pH. Therefore, we hypothesised that the reason why some Lupinus species are insensitive to calcareous soils is that they cope better with a high calcium (Ca) supply. We further hypothesized that they accumulate phosphorus (P) in mesophyll cells, and Ca in epidermal cells, thus avoiding the precipitation of calcium phosphates, which could make both Ca and P unavailable.

We grew different Lupinus species or genotypes of one species in nutrient solution or soil and measured biomass, leaf and root nutrient concentrations (including P and Ca), gas exchange, chlorophyll fluorescence, and P- and Ca-uptake rates. I also assessed cluster-root formation and activity under all treatments (pH, different calcium chloride and potassium bicarbonate concentrations, and combinations thereof). Finally, I determined the cell types in which Ca and P accumulate, using elemental X-ray microanalyses of leaf samples.

The result of a series of experiments showed that a high Ca supply caused a P imbalance in some Lupinus species, but Ca toxicity or the distribution of Ca and P between leaf cell types is not the key reason why some Lupinus species are sensitive to calcareous soils. Rather, the high pH is the direct reason and the strong buffering capacity of bicarbonate is the key factor determining if Lupinus species can survive in calcareous soils.

This research is supported by the ARC and IOA.

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

Project team: Miss Candy Taylor (leader; candy.taylor@research.uwa.edu.au), Professor Wallace Cowling, Dr Matthew Nelson, Dr Lars Kamphuis, Dr Jens Berger, Dr Gagan Garg, Professor Karam Singh, Dr Katia Stefanova, Dr Federico Ribalta, Dr Janine Croser, Ms Simone Wells, Ms Sabrina Tschirren, Ms Lyn Taylor

Collaborating organisations: [1]UWA; CSIRO (Floreat), DPIRD (South Perth), Curtin University (Bentley)

Owing to the recent and rapid domestication of narrow-leafed lupin, Australian and European varieties have limited genetic and phenotypic diversity for important agronomic traits, including flowering time. The majority of elite, modern cultivars are very early flowering, which adapts the crop to warm, short-season environments, such as the northern Western Australian (WA) wheat belt. However, to expand the lupin industry in Australia, particularly in the southern WA wheat belt and eastern states, it will become increasingly important to diversify flowering time to better adapt varieties to long-season environments with higher yield potential. This has been demonstrated through modelling, which indicates that delays of two to three weeks in flowering relative to current varieties could increase yields by as much as 16% in southern WA (Chen et al. 2017, European Journal of Agronomy, 89: 140-147) .

As little is yet known about the genetic regulation of time to flowering in narrow-leafed lupin, this project aims to: i) discover the extent of genetic and phenotypic diversity for this trait in a panel of more than 300 accessions, including domesticated varieties and wild accessions representing the species natural distribution within the Mediterranean Basin; and ii) better understand the genetic identity, variation, regulation and inheritance of the two currently known genes for flowering time (Ku and efl) in Australian narrow-leafed lupin breeding.

In 2018, we commenced work to locate the genomic position of the efl gene. This will eventually enable us to design genetic markers to make the selection of this gene more efficient in breeding and to better understand how flowering time is regulated via the efl gene in this species. A recombinant inbred line mapping population comprising 186 sixth generation individuals were scored for days to flowering and subject to genotyping. With this key work now completed, the next step is to map the position of the efl gene in 2019.

During 2018, several key second generation genetic populations derived from crosses between varieties with the Ku gene and its three alternative forms (or “alleles”) were also grown out. The aim of this was to discover whether more variation in flowering time is achievable if one of the three alternative variants is present instead of Ku. Analysis of these populations in the glasshouses indicates that one such alternative form of Ku may be particularly valuable for breeding, as it enables a wide diversity of other variations to be revealed (this is unlike Ku, which typically masks such variation). These key populations will now progress to field trials in 2019 with funding from The Council of Grain Growers Organisations Limited (COGGO).

Lastly, in 2018, a genome-wide association analysis was conducted to find areas of the genome that are significantly associated with flowering time variation. The study involved 377 lupin lines, including 170 Australian and European domestic types, plus 207 wild lines from the Mediterranean Basin. Several significant associations were identified and will be further assessed in 2019 to identify the underlying candidate genes.

This research is supported by UWA and GRDC (DAW00238).

16: Wild narrow-leafed lupins in flower. Photo: Candy Taylor.

Crop Genomics

Project team: Professor Dave Edwards (leader; dave.edwards@uwa.edu.au), Professor Jacqueline Batley[1] (leader; Jacqueline.batley@uwa.edu.au), Postdoc: Philipp Bayer, students: Andy Yuan, Armin Scheben, Habib Rijzaani, Ricky Hu, Clementine Merce, Cassie Fernandez, Robyn Anderson, Monica Danilevicz, Jacob Marsh

Collaborating organisations: UWA; International Pea Genome Sequencing Consortium; International Lentil Genome Sequencing Consortium

The applied bioinformatics group and the Batley laboratory have contributed to international projects to sequence the pea and lentil genomes, building on their expertise established sequencing the genomes of Brassica, wheat and chickpea.

These genome 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 2018, the genome of bread wheat was published in Science and an issue with genome annotation for disease resistance genes was published in Nature Plants.

The genomics research has been extended to sequence the pangenomes of important crop species. The pangenomes of canola and sesame were published in 2018 while the pangenome of bread wheat was published in 2017. 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.

Plant information systems

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

Collaborating organisations: UWA; International Wheat Information System Expert Working Group; International Rice Informatics Consortium; 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, co-chair of the wheat information system expert working group, and on the advisory committee for the international rice informatics consortium.

In 2018 we published a database to host genome diversity information for wheat and canola.

An integrated platform for rapid genetic gain in pulse crops

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

Collaborating organisations: UWA; Pulse Breeding Australia – SARDI, Tamworth, Horsham; Australian Grains Genebank; University of Tasmania; INRA Dijon

Within UWA175, an integrated breeding platform has been developed, incorporating rapid generation cycling in pulses with high throughput screening and phenotyping to discriminate breeding material with tolerance to biotic (*Botrytis* and *Ascochyta*) and abiotic (subsoil toxicities, herbicide tolerance and chilling) constraints. In 2018, this technology was transferred to faba bean and implemented in all four Pulse Breeding Australia (PBA) breeding programs, giving Australia a unique comparative advantage in pulse breeding. Multiple recombinant inbred populations have been developed and delivered to PBA programs, with more than 35,000 individuals processed to date. This has greatly assisted the rapid introgression of key traits including salinity, heat and drought tolerance in chickpea, herbicide tolerance in lentils, ascochyta blight resistance in lentils, faba bean and chickpea, flowering phenology in field pea and root-lesion nematode resistance in chickpea.

Within UWA175 we also undertake research to characterise cytological inter-specific barriers following crossing of chickpea and *C. echinospermum*. This information will enable us to develop predictions of hybridisation success.

This research is supported by GRDC.

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]

Collaborating organisations: [1]UWA; [2]Australian Herbicide Resistance Initiative (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.

Numerous studies have assessed the capability of remote sensing technologies in discriminating plant species based on their shape, texture and colour. Additionally, images from UAV platforms and data from ultrasonic sensors have been used for vegetation detection. Sensor technology is growing fast and sensors such as LiDAR are becoming more reliable. This opens new horizons for detecting taller plants in a canopy at late phenological stages, by producing 3D data with higher resolution.

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 the crop in wheat crop fields using LiDAR and map their locations for weed management in the following season.

During the 2018 winter crop harvest season a crop field survey was performed in the Western Australian Central Wheatbelt 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.

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

17: All present weed species in the crop field were identified and the weed/crop heights were measured during the 2018 field survey.

Can castor plants tolerate salinity stress?

Project team: Hackett Professor Kadambot Siddique[1] (leader; kadambot.siddique@uwa.edu.au), Mr Junlin Zheng[2], Dr Yinglong Chen[1], Andrew Farson[3]

Collaborating organisations: [1]UWA; [2]Shenyang Agricultural University, China; [3]Zenith Australia Group

Soil salinity is one of the major environmental constraints threating Western Australia's agriculture. More than one million hectares of agricultural land in Western Australia are impacted by soil salinity. The loss of agricultural production induced by salinity stress is estimated to be worth at least $519 million per year. The objectives of this study were to (a) identify the salinity tolerance of castor bean genotypes, and (b) evaluate the effects of salt stress on plant growth and development. Two experiments were conducted at UWA in glasshouses with controlled temperatures from March to May 2018 to evaluate the salinity tolerance among five castor been genotypes (Experiment 1) and compare salinity tolerance of bread wheat with castor plants (Experiment 2).

Experiment 1 showed that salinity stress significantly affected plant growth and dry matter production, but the genotypes responded differently. Plant heights were measured from 24 to 81 days after sowing. All genotypes were taller under non-salt treatment, followed by the lowest salt treatment (50 mM), compared to other two higher NaCl treatments (100 and 150 mM). Shoot growth was suppressed by salt stress as low as 50 mM. Surprisingly, castor plants survived under all tested salt concentrations up to 150 mM indicating they are relatively tolerant to salinity. Among the five genotypes, the imported Chinese genotype ('Zibo' 2017) produced larger plants than the other genotypes regardless of salt treatments. Plants of genotype #2 (collected from Forrestdale) were relatively smaller. Plant tissue Na+ and K+ concentration were also measured with higher Na concentration in the highest salt treatment for #3 (N/Fremantle), while no such difference was observed for 'Zibo'.

Compared to the non-salt control, wheat plants had some effects from salt stress with no significant differences between the three salt treatments in terms of wheat shoot growth (height, biomass) (Experiment 2).

The salinity experiments showed significant effects of salinity on plant growth. The three salt levels (50, 100 and 150 mM) had similar effects on plant growth indicating the castor bean plants have good tolerance capacity for relatively high salinity stress. Results also confirmed that bread wheat is more tolerant to salinity than castor bean.

This research is supported by Virtue Australia Foundation.


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18: Castor bean plants were tested for salinity tolerance in a glasshouse at UWA, Perth. Photo: Yinglong Chen.

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21

Dissecting root trait variability in maize genotypes using the semi-hydroponic phenotyping platform

Project team: Dr Yinglong Chen[1] (leader; yinglong.chen@uwa.edu.au), Mr Sheng Qiao[2,3], Dr Yan Fang[2,3], Ms Aijiao Wu[2,3], Professor Bingcheng Xu[2,3], Professor Suiqi Zhang[2,3], Professor Xiping Deng[2,3], Dr Ivica Djalovic[4], 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, CAS and Ministry of Water Resources, China; [4]Institute of Field and Vegetable Crops, Serbia

Crop growth and grain yield rely on the capacity of the root system to forage and capture soil resources. Alterations to root growth and root system architecture are a critical adaptive strategy of crops to cope with drought, soil infertility and other edaphic stresses. Therefore, it is important to breed cultivars that have root systems with improved adaptation to edaphic stresses and water and nutrient efficiencies. Maize (*Zea mays* L.) is widely planted around the world with annual productivity of ~700 million metric tons.

This study used an established semi-hydroponic phenotyping technique to assess root trait variability across 174 maize genotypes, including 113 cultivars and 11 breeding lines from northern China and 50 Serbian hybrids. The results showed that large variation in root architecture traits was observed among the tested genotypes 28 days after transplanting. Sixteen of the characterized traits had coefficients of variation greater than 0.25. Root traits including total root length, root length at various depths, total shoot mass and nodal root angle, should be considered in maize breeding programs.

This study identified genotypic variation in root architecture traits in a diverse genotypes of maize. Selected genotypes with contrasting root morphological traits have been used in subsequent studies including validation of root trait variability among the genotypes in rhizoboxes filled with soil, investigation of root responses to drought, low phosphorus supply and salt stress at Northwest A&F University.

This research is supported by National Natural Science Foundation of China, CAS "100 Talent" Program.

19 : Master student Sheng Qiao (second left) demonstrated non-destructive observation of maize root systems using the semi-hydroponic phenotyping platform, to a group of visiting scientists (from left: Dr Michel E Ghanem of ICARDA, Morocco; Master student Mr Sheng Qiao of NWAFU, Adjunct Prof Neil Turner of UWA, Australia; Prof Henry Nguyen of University of Missouri, USA; Adjunct Professor Jairo Palta of UWA, and CSIRO, Australia; and Prof Vara Prasad of Kansas State University, USA). Photo: Yinglong Chen.

Pre-breeding of canola and peas

Project team: Professor Wallace Cowling (leader; wallace.cowling@uwa.edu.au), Ms Jasenka Vuksik, Ms Roz Ezzy

Collaborating organisations: UWA; NPZ Australia Pty Ltd (subsidiary of NPZ Lembke, Germany)

Pre-breeding of canola and peas is being developed using a new approach based on best linear unbiased prediction (BLUP) of breeding values (EBVs). EBVs for yield and other complex traits are combined into an economic index of genetic value in $/ha. BLUP or genomic BLUP values are calculated for grain yield, disease resistance and seed quality. Data are integrated across cycles of selection to provide improved predictions. Optimised mating designs from animal breeding, based on optimal contribution selection (OCS) on an economic index are being used. OCS provided superior genetic gain with reduced rates of population inbreeding and improved long-term genetic gain.

Research on the methodology uses field peas as a model crop. MSc student Felipe Castro is undertaking a project to cross the next generation for recurrent selection with OCS. He will measure traits in the progeny in the field and evaluate a new method of bivariate analysis for improving the accuracy of EBVs.

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.

20: MSc student Felipe Castro crossing peas in the glasshouse. Photo: Wallace Cowling.

Self-pollinating Lucerne

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

Collaborating organisations: [1]UWA; [2]SuperSeed Technologies (SST)

The literature states that lucerne seed production in Australia benefits significantly from the presence of suitable pollinating insects (for example, https://www.agrifutures.com.au/wp-content/uploads/publications/10-123.pdf)

In early work with a wide range of species, an open pollinated variety of lucerne (SARDI 10) was the only species and variety tested that showed a response to bees (see Hamblin et al. 2018). This result agrees with the literature. However, a very diverse population involving 30 lines of lucerne of diverse origin were used to develop a population that has now been selected in the absence of bees, and have set significant numbers of pods. These are highly likely to be able to seed large amounts of seed in the absence of bees. This will be determined this year in an experiment where the plants are grown with and without bees to determine if there is a response in seed production due to the presence of bees. If there is not, then self-pollinating types of lucerne will have been identified.

This research is supported by SuperSeed Technologies, and RIDRC.

21: Stems of SARDI 10 grown in the absence of bees, note no pods.

22

Sequencing historic crop virus isolates

Project team: Adjunct Professor Roger Jones[1] (leader; roger.jones@uwa.edu.au), Dr Ian Adams[2], Professor Neil Boonham[3], Emeritus Professor Adrian Gibbs[4], Professor Cesar Fribourg[5]

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

Additional Collaborators: Ing. Franklin Santillan (Universidad de Quenca, Quenca, Ecuador), Dr Jorge Abad (Universidad Nacional Agraria, La Molina, Lima, Peru), Dr Adrian Fox (FERA Science LTD, York, UK), Dr Monica Kehoe (Department of Primary Industry and Regional Development, South Perth, Australia), Dr Solomon Maina (University of Western Australia, Perth, Australia)

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 with new sequences of the same virus to determine its rate of mutation and use this to date when divergences occurred, some of which 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 1970s and early 1980s. A wide range of viruses from diverse crops in the Andean region of South America and Europe were maintained for 30-40 years in in the FERA virus isolate collection in the United Kingdom. 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 1970s was identified and a biological and phylogenetic study undertaken comparing its old and new isolates. Where sufficient genomes were available dating studies were undertaken.

Where enough virus genomes were available, these studies are being published as complete papers, but when only a few were available, as genome announcements (see 2018 Publication List).

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

22: Before they were sequenced, isolates of several viruses were preserved over silica gel inside this tin for 38 years after being sent from Peru to England. Photo: Neil Boonham, FERA Science ltd, York UK.

How much chlorophyll per unit leaf area is enough?

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

Collaborating organisations: [1]UWA; [2]SuperSeed Technologies (SST); Australian Grain Technologies (AGT); [3]Yaruna Research

When competing against other species or different genotypes of the same species, it may be advantageous to harvest more light than required; for maximum growth and to make this resource unavailable to other individuals. In a crop however, the objective is not competitive advantage for the individual, but rather grain yield per unit area.

In 2018 it was found that environmental factors, sites, years and plant density had little effect on the expression of chlorophyll per unit leaf area across a wide range of genotypes. It is highly heritable and therefore easily selected for. The next phase is to determine whether it is a good prediction of yield potential at crop densities.

This research is supported by SuperSeed Technologies, and RIRDC.

23: Low chlorophyll, high tillering line.

24: High chlorophyll, low tillering line.

Relationship between fruit size of apples and butternut pumpkins and seed number per fruit

Project team: Adjunct Professor John Hamblin[1,2] (leader; john.hamblin@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]SuperSeed Technologies (SST); Chapman Valley Primary School years 4-6

It is commonly considered that for apples and butternut pumpkins, size and quality reflect seed number and therefore pollination.

Over the last few years data have been collected on commercial fruit weight and seed number. The results of this study clearly show that, contrary to expectations, there is no relationship between fruit size and seed number. It seems that there are significant differences among varieties; this has not been adequately accounted for in most research.

Improving yield by optimising energy use efficiency

Project team: Dr Nicolas Taylor (leader; nicolas.taylor@uwa.edu.au) and Prof Harvey Millar (leader; harvey.millar@uwa.edu.au), Dr Elke Stroeher, Sunday Tang

Collaborating organisations: UWA; Australian National University, Canberra; The University of Adelaide, Adelaide; CIMMYT, Mexico

The International Wheat Yield Partnership (IWYP; https://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 2018, 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 IWYC and GRDC.

25: Dr Elke Stroeher extracting protein 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] (leader; nicolas.taylor@uwa.edu.au), Dr Ben Biddulph[2], Dr Nik Callow[1], Brenton Leske[1], Professor Harvey Millar[1], Professor Tim Colmer[1]

Collaborating organisations: [1]UWA; Centre for eResearch and Digital Innovation (CeRDI) at Federation University Australia; [2]DPIRD Western Australia; CSIRO; University of New England; 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 2018 Dale research site that will be integrated into AgReFed (https://www.agrefed.org.au). This will allow the analysis of biological and yield data with time-series environmental data, sensor data, hyperspectral imagery data, and spatial data, through the implementation of data exchange and metadata standards, controlled vocabularies, and services over the data.

This research is supported by Australian Research Data Commons.

26: Yimin Wang collecting canopy hyperspectral reflectance data at the DPIRD Dale research site.

Progression of plant-parasitic nematodes and foliar and root diseases under long-term no-tillage with different crop rotations

Project team: Dr Ken Flower[1,4] (leader; ken.flower@uwa.edu.au), Dr Daniel Hüberli[2], Dr Sarah Collins[2], Geoff Thomas[2], Dr Phil Ward[3], Mr Neil Cordingley[2]

Collaborating organisations: [1]UWA, [2]Department of Primary Industries and Regional development, [3]CSIRO, [4]Western Australian No-Tillage farmers Association (WANTFA),

The trial was based at the WA College of Agriculture Cunderdin. Assessments ran from 2007 to 2016 trial was started in 2007 and. The research compared a diverse crop rotation (cereal/legume/brassica) with a 'typical' farmer rotation (cereal/cereal/legume or fallow), a cereal rotation (rotated between wheat, barley and oats) and wheat monoculture.

Levels of disease were assessed by the SARDI PREDICTA®B DNA analysis method. Root lesion nematode (*Pratylenchus neglectus*) and *Pythium* levels increased most in the diverse rotation. This was followed by the wheat monoculture and levels decreased slightly in the farmer and cereal rotations. The combination of canola and wheat, along with susceptible chickpea, favoured root lesion nematode. In comparison, fallow and lupin in the farmer rotation were most effective at reducing levels. By the end of the assessment period (2016), there was significantly greater *Rhizoctonia solani* in the soil following cereals compared with canola, chickpea and fallow. Although, the break crops appeared to have had a relatively short term effect on amounts of *R. solani*. Over the nine years, *Fusarium* spp. DNA in the soil increased most in the cereal rotation and wheat monoculture; it hardly changed in the farmer and diverse rotations and pasture.

This research was supported by GRDC.

2

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.

Environmental factors limiting the productivity of serradella in southern Australia

Project team: Daniel Kidd (leader; daniel.kidd@research.uwa.edu.au), Associate Professor Megan Ryan, Tim Colmer, Richard Simpson

Collaborating organisations: [1]UWA; CSIRO Agriculture; NSW Department of Primary Industries; Murdoch University

Serradella is a high quality pasture legume commonly used on sandy, infertile soils. It has been shown to have a lower requirement for phosphorus fertiliser compared to other pasture options due to its extensive root system. It is possible to manage permanent pasture systems with lower fertiliser inputs by using serradella, however its potential area of adaptation could be limited by environmental constraints such as aluminium and manganese toxicity, waterlogging and cold winter temperatures. This study aims to identify differences among serradella cultivars to these constraints and will provide greater clarity about their potential use in permanent pastures in southern Australia.

A large experimental program was completed in 2018. This addressed the physiological and phenotypic responses of serradella cultivars to cold temperatures; as they are generally described as being slow to establish under cold conditions. To test this, the program comprised two experiments that examined different stages of plant development where cold temperatures might be an issue. The first assessed the rate of germination and emergence, dry matter (DM) production and nodulation for 35 cultivars of serradella and other pasture legumes. Germination rate was recorded across four temperature regimes, reflective of mid-winter through to mid-spring conditions. The second experiment assessed relative growth rates of some of the more popular commercial serradella cultivars at two temperature regimes and compared their growth to more winter-active pasture legumes such as lucerne and subterranean clover. Based on the findings from these experiments there is no evidence (under controlled conditions) to suggest the productivity of serradella cultivars will be limited by cold temperatures in isolation and this environmental constraint should not limit their area of adaptation.

Serradellas also have a reputation for having poor waterlogging tolerance and are therefore regarded as an inappropriate choice of pasture legume for the high rainfall zones. However, again, there appears to be only anecdotal evidence for these observations. Therefore investigations of the waterlogging tolerance of 3 species of serradella (yellow, French and slender) under controlled conditions and compared their growth to known waterlogging tolerant species, balansa clover, were undertaken. Serradella managed to maintain shoot growth under waterlogged conditions however there was a significant reduction in root growth (compared to the control) which limited its ability to recover quickly once waterlogged conditions were removed. This suggests that serradella growth will be reduced by temporary inundation compared to more tolerant species.

The Project Lead, Daniel Kidd, received an Institute of Agriculture Calenup scholarship to implement a field trial at Merredin research station. The experiment was used as an opportunity to benchmark the aluminium (Al) tolerance of serradella cultivars and to compare the findings with those he achieved under controlled conditions. This experiment assessed root and shoot growth on an acid sandplain soil with high concentrations of subsoil Al and compared this to plots where lime had increased pH and thus reduced plant available Al. It also measured root exudation (which is rarely measured in the field) and soil water use as well as other agronomic characters.

This research is supported by Rural Research and Development for Profit – Department of Agriculture & Water resources, MLA, AWI, and Dairy Australia.

1: PhD student Daniel Kidd checking the aeration tubes in his solution culture experiment assessing waterlogging tolerance in serradella. Photo: Robert Creasey.

Phosphorus Efficient Pastures: delivering high nitrogen and water use efficiency, and reducing cost of production across southern Australia

Project team: Associate Professor Megan Ryan[1] (leader; megan.ryan@uwa.edu.au), Dr Richard Simpson[2] (leader), Professor Tim Colmer[1], Associate Professor Parwinder Kaur[1], Associate Professor Willie Erskine[1], Mr Daniel Kidd[1], Dr Richard Hayes[3], Dr Sue Boschma[3], Professor John Howieson[4], Dr Brad Nutt[4]

Collaborating organisations: [1]UWA; [2]CSIRO Agriculture; [3]NSW Department of Primary Industries; [4]Murdoch University

The aim of the project is to reduce the phosphorus (P)-dependence of Australian temperate pastures. One area of investigation is the potential to expand the use of pasture legumes that have lower P requirements than subterranean clover (*Trifolium subterraneum*). The serradellas (*Ornithopus spp.*) are the focus of this research.

In 2018, the UWA team undertook several glasshouse experiments to investigate the range in adaptation within the three main species of serradella to constraints that could limit their growth and persistence, particularly in eastern Australia. These included tolerance to high iron, aluminium and manganese levels in soil, cold temperatures and waterlogging. Serradella phenology was also investigated in a field experiment at the Shenton Park field station, with results compared to sites in eastern Australia.

This research is supported by Rural Research and Development for Profit – Department of Agriculture & Water Resources, MLA, AWI, and Dairy Australia.

2: The serradella phenology experiment at the Shenton Park field station.

Managing subterranean clover red leaf syndrome (SbDV) in Western Australia – Stage 1

Project team: Dr Kevin Foster[1] (leader; kevin.Foster@uwa.edu.au), Mr Paul Sanford[2], Associate Professor Megan Ryan[1], Dr Brenda Coutts[2], Dr Ben Congdon[2]

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

DPIRD and UWA investigated the subclover red leaf disease outbreak in Western Australia in 2017 with spring testing of subterranean clover and other species from 22 growers in 15 locations tested for the presence of viruses. From the subterranean clover plants tested, 80% with obvious red leaves were infected with Soybean dwarf virus (SbDV) compared to just 2% without obvious symptoms. SbDV is spread by aphids and is known to infect subclover. SbDV is not seed-borne and is therefore not present in the seed bank or in commercial seed stocks. SbDV predominantly infects legume species and does not infect grasses. The Diagnostic Laboratory Services (DDLS) at DPIRD has now designed two molecular diagnostic protocols that offer sensitive and rapid detection of SbDV in plant tissue. These new methods were used to test samples in 2017-2018. In addition, a field trial was set up in 2018 to examine susceptibility and sensitivity of various pasture legume species to SbDV infection. For further information see: https://www.agric.wa.gov.au/crop-diseases/subterranean-clover-red-leaf-syndrome-caused-soybean-dwarf-virus

This research is supported by MLA and AWI.

3: Subterranean clover plant SbDV-infected with red leaves. Note that the reddening occurs from the leaf margins inwards.

Investigating mechanisms through which methanogenesis is inhibited by plant secondary compounds

Project team: Professor Phil Vercoe (leader; philip.vercoe@uwa.edu.au), Muhammad Shoaib Khan, Dr Zoey Durmic, Associate Professor Parwinder Kaur

Collaborating organisations: UWA; University of Agriculture Faisalabad, Pakistan

Methane (CH_4) is 27 times more potent as a greenhouse gas than carbon dioxide (CO_2). One of the major sources of methane emissions is enteric fermentation in ruminant livestock. Indeed, it is thought that methane produced from ruminants accounts for 12% of Australia's total greenhouse gas emissions (on CO_2-equivalent basis).

Various strategies have been suggested for the prevention of methane production by Australia's sheep and cattle, and plant secondary compounds are getting serious attention because of consumers perceiving them as 'natural' and 'eco-friendly'. Importantly, our initial findings suggest that, among these plant-based compounds, the essential oils can reduce methane emissions without affecting rumen function, so the animals can digest their feed normally. However, there is little information on how these compounds operate in rumen.

The aim of this project is to explore the mechanism(s) of action of the essential oils using the latest molecular technologies, metagenomics and meta transcriptomics. The overarching hypothesis is that all of the essential oils that reduce methane production use the same mechanism of action, whether they affect the methane producing bacteria in the rumen (the 'methanogens') directly or indirectly. In the first experiment, various anti-methanogenic compounds that were thought to use different modes of action(s) and by studying their effects during incubation in a 'test-tube rumen' for 24 hours ('batch culture') were screened. In the second experiment, the best methane inhibitors revealed by batch culture system, and a candidate essential oil, in the 'RUSITEC', a continuous culture, artificial rumen was studied. This system allowed the compounds to be studied over 15 days, during which time changes in pH as well as total gas, methane and hydrogen production were measured. Daily samples were also taken of the liquid and solid phases of the fermentation mix, these were preserved at -80°C in preparation for the next phase of the project; the metagenomic and meta transcriptomic analysis of the effects of the compounds on the rumen microbial population.

This research is supported by UWA.

4: Testing of different anti-methanogenic compounds in continuous fermentation system (the artificial rumen, or 'RUSITEC').

Banana and guava plant waste reduce methane emissions in continuous rumen culture (Rusitec)

Project team: Professor Phil Vercoe (leader; philip.vercoe@uwa.edu.au), Ms Amriana Hifizah, Professor Graeme Martin, Dr Zoey Durmic

Collaborating organisations: UWA; Tass 1 Trees Nursery Farm, Middle Swan, Perth; DPIRD, Wallal Station, Broome (Dr. Clinton Revell)

Methane (CH_4) is a direct contributor to global warming and a normal end-product of rumen fermentation emitted by sheep, goats and cattle. Methane emissions are predicted to increase as the human population increases and the demand for livestock products increases. In Indonesia, the availability of feed for livestock is likely to become limiting in production systems because the demand for cropping land is increasing. Therefore, this project aims to investigate waste from tropical horticultural crops as an alternative feed supply, and evaluate the effects of these waste products on methane production in the rumen.

The first experiments used batch culture, a system for screening plant material by rumen fermentation for 24 hours in a test tube. Various mixtures of leucaena (a standard forage) with horticultural waste (banana and guava) were tested to find the best combinations: those that reduce CH_4 production but had little effect on 'fermentability' (a measure of nutritional potential for the animal). The results of these experiments suggested that follow up trials should use mixtures of 25:75 guava: leucaena, 75:25 banana: leucaena, and 25:5:70 guava: banana: leucaena.

The next stage in the process was to move from batch culture to a more realistic fermentation system: an artificial rumen (Rusitec) in which potential feeds are fermented for 20 days. The 25:75 guava: leucaena mixture reduced CH_4 production by 61 % without affecting the fermentation characteristics of the feed. The 25:5:70 guava: banana: leucaena mixture reduced CH_4 by even more (77%) with only minor reductions in measures of fermentation. The greatest reduction in CH_4 (92%) was seen with the 75:25 banana: leucaena mixture, but fermentation was significantly depressed.

It appears that 25:75 guava: leucaena and 25:5:70 guava: banana: leucaena have the greatest potential as alternative feeds that will reduce CH_4 production while maintaining animal productivity. The next stage of this project will be to trial these mixes with sheep or goats.

This research is supported by LPDP (Indonesia Endowment Fund for Education) and School of Agriculture and Environment, University of Western Australia.

5: Amriana Hifizah sampling the fermentation liquid from the Rusitec. Photo: Shohaib Khan.

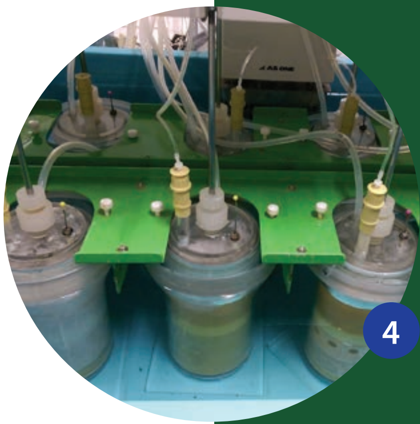
The effects of molasses-based vinasse products (Dunder, Wilmar BioEthanol) on *in vitro* ruminal fermentability

Project team: Dr Zoey Durmic (leader; zoey.durmic@uwa.edu.au), Dr Joy Vadhanabhuti, Mr Hatem Al-Khazraji, Dr Liana Lillford[2]

Collaborating organisations: [1]UWA; [2]Wilmar Sugar Pty Ltd

Commercial-in-confidence.

This research is supported by Wilmar Sugar Pty Ltd.



The effect of inoculating shipper pellets fed to Merino wethers with *Bacillus amyloliquefaciens* strain H57

Project team: Professor Philip Vercoe[1] (leader; philip.vercoe@uwa.edu.au), Dr Zoey Durmic[1], Dr John Milton, Dr Joy Vadhanabhuti, Dr Bidhuyt Banik, Mr Hatem Al-Khazraji, Dr Mathew Callahan[2]

Collaborating organisations: [1]UWA; [2]Ridley Agriproducts Pty Ltd

Commercial-in-confidence.

This research is supported by Ridley Agriproducts Pty Ltd.

6: Sheep consuming probiotic-enriched pellet.

Can *Khaya senegalensis* improve gut health in sheep?

Project team: Suyog Subedi (leader; suyog.subedi@research.uwa.edu.au), Professor Graeme Martin, Professor Philip Vercoe, Dr Zoey Durmic, Dr Stephanie Payne

Collaborating organisations: UWA; CSIRO; DPIRD; Bioactive Laboratories

Western Australia is home to almost 13.8 million sheep and lambs raised by more than 5000 sheep producers. The sheep industry is big, contributing almost 50% of the gross value of production attributed to all livestock industries in the state. However, this industry is often marred by internal parasites and gut diseases causing a huge financial loss. It is estimated that the internal parasite alone causes a loss of around $435.9 million annually. To add to that, drug resistance and demand for organic animal products has made worm control a daunting task. The same applies for antibiotics, there is a substantial pressure to ban antibiotics in food animal to livestock production, but simply banning it is not a solution. These issues are becoming more urgent with the realisation that there are more human mouths to feed and that the demand for animal-derived food products is increasing. To ensure that animal production keeps pace with the demand, there is a need to preserve the efficacy of the existing medications and to search for alternatives.

Plant products have been used throughout history to treat human and animal diseases. There is now substantial scientific evidence to support the fact that some secondary plant compounds can be used as an alternative. There are a number of benefits to choosing plant compounds over traditional synthetic drugs. Therefore, there is a growing trend to validate their efficacy by measurement of bioactivity and identification of the active molecules in phytochemical studies. Results from previous studies have indicated that a tree, *Khaya senegalensis*, may have a range of bioactive properties. For example, extracts from this plant can affect gram positive and gram negative bacteria in humans, as well as have anthelmintic properties that combat gastrointestinal worms of sheep. There is no information about the chemical nature of the active compounds or the mechanisms of action involved. The effect of *K. senegalensis* extracts on major pathogenic gut bacteria in sheep and lactic acidosis has not been studied. This project will isolate and identify compound(s) from *K. senegalensis*, study their anthelmintic properties, and try to elucidate the underlying mechanism of action. It will also examine the effects of whole plant material as well as particular compounds for their effects on major pathogenic strains of gut bacteria, with a focus on ruminal lactic acid formation. The combinations of these studies will enable assessment of the potential of *K. senegalensis* for managing sheep gut health.

In 2018, Project Leader, Suyog Subedi, successfully wrote and presented a research proposal that was approved by supervisors and GRS. Following the required approvals, a detailed research protocol was developed and a collaboration was formed with CSIRO, DPIRD and Bioactive laboratories. While these activities were underway, Suyog Subedi received training on various laboratories skills essential for the project. Early 2019 saw the collection of the required plant material and extraction using various solvent system. The next steps will be the microbiological bioassay of the extract.

This research is supported by UWA and Bioactive Laboratories.

7: Training on microbiological procedures.

Rumen epithelial mitochondria could help identify more feed-efficient sheep

Project team: Dr Jude Bond[2] (leader; jude.bond@dpi.nsw.gov.au), Umair Hassan Khan[1], Professor Phil Vercoe[1], Professor Hutton Oddy[2], Professor Brian Paul Dalrymple[1], Nick Hudson[3]

Collaborating organisations: [1]UWA; [2]University of New England, Armidale; [3]University of Queensland, Brisbane

The rumen plays an important role in feed efficiency and methane production because it is the main site for microbial fermentation, feed digestion and production of short-chain fatty acids (SCFAs), the main source of energy in ruminants. The SCFAs are mainly absorbed from the rumen and metabolized in the rumen epithelium, liver and peripheral tissues. They are absorbed by simple diffusion as well as protein-mediated transport. Ketogenic enzymes in mitochondria play a crucial role in the metabolism of SCFAs to ketone bodies, another important source of energy within the body. Variation in the ability of the rumen epithelium to absorb and metabolize SCFAs should be reflected in higher expression of genes involved in their absorption and metabolism.

The rumen is also the principal source of methane; a major contributor to the environmental footprint of agriculture. In sheep, for example, more than 87 % of the methane produced comes from the rumen. In addition to being a greenhouse gas, methane emitted from the rumen also represents a loss of between 7-12 % of gross energy in sheep. Therefore, reducing methane production would provide dual benefits; improving the efficiency of energy utilization and reducing global warming.

One possibility is to use genetic selection to reduce methane emissions but, for this approach to be efficient, there is a need to first understand the physiological and genetic basis of variation among sheep in methane production. This project focussed on the mitochondria, a critical component of epithelial cells that are thought to be involved in the relationship between methane emission and efficiency. Mitochondria are crucial to many cellular metabolic pathways because their main role is to provide energy in the form of ATP via oxidative phosphorylation. Variation in the number, structure and function of mitochondria, among the cells and tissues of sheep, reflect their responses to energy needs. Just as the energy demands of cells can vary during development and differentiation, and in response to physiological and environmental alterations, the number of mitochondria can also vary through complex, finely regulated processes. It is therefore possible that the number of mitochondria in a rumen epithelial cell, and the gene expression by those mitochondria, will lead us to metabolically efficient animals.

This study will reveal relationships between protein abundance, gene expression and mitochondrial content in the rumen epithelium, and show how those relationship vary with sheep phenotype. The phenotypic relationships will allow us to identify regions of the genome, or perhaps even genes, that explain variations among sheep in digestive function and characteristics of rumen anatomy. We should be able to develop cellular markers for selection programs to reduce CH_4 emissions and improve productivity.

Producers will benefit from this with reduced feed costs as well as rewards through carbon market schemes.

This research is supported by MLA.

8: Working on culture preparation in the Marshall Centre.

Maximising the reproductive potential of the sheep meat industry by eliminating high oestrogen clover: more live lambs on the ground – Phase I

Project team: Associate Professor Megan Ryan (leader; megan.ryan@uwa.edu.au), Dr Kevin Foster, Professor Phil Vercoe, Dr Zoey Durmic, Dr Dominique Blanche, Professor Graeme Martin

In a recent survey of pastures across southern Australia, UWA researchers found that many contained out-dated cultivars of subterranean clover (for example, Yarloop, Dwalganup, Geraldton and Dinninup), which contain high levels of the oestrogen formononetin in their green leaves. Continued exposure to high-oestrogen clovers can have serious and long-term impacts for grazing sheep. In ewes these include temporary infertility and, if grazing occurs for prolonged periods of time, permanent infertility. Grazing these highly oestrogenic pastures can, unfortunately, also cause an increase in ewe mortality, uterine prolapse, difficult births and post-natal lamb mortality.

After the project commenced in mid-2018, Kevin Foster spread the word about this issue through field-days, industry forum updates and paddock walks in Western Australia, South Australia and New South Wales. Through discussions with consultants and agronomists, it was clear that few were familiar with this issue or were able to identify these highly oestrogenic subterranean clovers cultivars in the field.

Farmers submitted leaf samples of their pastures for identification and oestrogen measurement. Around 25% of samples submitted had levels of oestrogens above the current recommended levels for sheep. It should be noted that naturalised variants of subterranean clover that have evolved locally (from natural crossing events) were also found and may also occur widely; some of these are also highly oestrogenic.

Overall, in 2018, the project established excellent links with grower groups and producers in each state interested in follow up activities scheduled for 2019 focussing on the problems and management of high oestrogenic subterranean clover cultivars or their variants.

This research is supported by MLA Donor Company and FF2050.

9: Dinninup sward.

Elucidating causes of diarrhoea in sheep

Project team: Adjunct Professor Johan Greeff[1,2] (leader; johan.greeff@dpird.wa.gov.au), Professor Graeme Martin[1] (leader; graeme.martin@uwa.edu.au), Dr Xiaoyan Niu[4], Dr Shimin Liu[1], Dr Dieter Palmer[2]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]AWI; [4]Shanxi Provincial Government, China

The worm-flystrike disease complex costs the Australian Merino sheep industry $600m per year. As a basic resource, we have Adjunct Professor Johan Greeff's world-unique flock of Merinos that has been genetically selected for 25+ years for resistance to gastro-intestinal (helminth) worms. These worms reduce productivity and cause diarrhoea that attracts blowflies, leading to flystrike. Around the world, medication is now becoming useless because, in all types of farm animals, the worms are becoming resistant to anthelminthic drugs. For Merino sheep in Australia, the problem is worse because prevention of flystrike by 'mulesing' is socially unacceptable.

However, many worm-resistant sheep still have diarrhoea because they are hypersensitive to the few worms that they still carry. In the flystrike-resistant sheep, we don't know how the resistance works.

In this part of the project, Dr. Xiaoyan Niu (Shanxi Academy of Agricultural Science, China) is using histological techniques to investigate the part played by cells from the immune system. She is quantifying mast cells and eosinophils in three parts of the sheep gut: abomasum, duodenum and colon.

This project aims to identify the key components of the immune response that causes the hypersensitivity to worms, and identify an easily measured indicator that can be used as breeding traits to develop a selection criterion for low susceptibility to diarrhoea.

This research is supported by DPIRD; AWI; and Shanxi Provincial Government, China.

10: Collecting samples from Merino sheep at the DPIRD Research Station, Katanning. From left to right: Shimin Liu, Johan Greef, Xue Wang, and Xiaoyan Niu.

Role of the gut microbiome in the worm-diarrhoea-flystrike disease complex in sheep

Project team: Dr Erwin Paz Muñoz[1] (leader; erwin.pazmunoz@uwa.edu.au), Dr Alfred Tay[3], Adjunct Professor Johan Greeff[1,2], Associate Professor David Groth[4], Dr Shimin Liu[1], Dr Dieter Palmer[2], Dr Eng Chua[3], Professor Graeme Martin[1]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]Marshall Centre; [4]Curtin University

Sheep with gut worm infections have diarrhoea that attracts the blowfly, *Lucilia cuprina*. The fly lays eggs on the wool and a massive larvae infestation follows ('flystrike'). This disease complex has profound impacts on animal health, welfare and productivity, and imposes massive annual costs (up to $600,000 per annum for Australia alone).

Breeding for resistance to worm infection has proven to be a highly effective strategy. Sheep are bred to have the phenotype of low numbers of worm eggs in their faeces (faecal egg count, or FEC). The Rylington Merino flock at DPIRD's Mount Barker Research Station is probably the most worm-resistant Merino flock in the world based on breeding selection. Our research is part of a program in which we are trying to understand how the genetic selection works and how it changes the genes in the sheep and perhaps the worms. We are looking into the role of the gut microbiomes in both the sheep and the worms to find out whether they play a role in the generation of diarrhoea.

Tissues and gut contents were collected from various parts of the digestive tract of 38 Rylington Merino sheep, including animals that were susceptible to worms, resistant to worms, or resistant to worms but hypersensitive to the few worms that they still carried. The hypersensitive animals are a problem because they still have diarrhoea despite the small numbers of worms in their system.

The project hypothesis is that these Rylington phenotypes will reveal sample differences in their gut microbiome that explain the responses to selection for worm resistance. DNA has been extracted and processed for 'Next-Generation Sequencing' and the project is moving towards the bioinformatic analysis stage.

This research is supported by DPIRD and UWA.

11: Shamshad, Prapawan and Erwin visit the Katanning Abattoir to collect sheep guts for parasite isolation.

Roles of small, non-coding RNAs in the responses of worm-resistant Merino sheep to infection with worms

Project team: Adjunct Professor Johan Greeff[1,2] (leader; johan.greeff@.dpird.wa.gov.au), Mr Shamshad Ul Hassan[1], Dr Erwin Alejandro Paz Muñoz[1], Professor Graeme Martin[1], Dr Parwinder Kaur[1], Dr Alfred Chin Yen Tay[1]

Collaborating organisations: [1]UWA; [2]DPIRD; [3]Marshall Centre

The sheep industry is a major contributor to the Australian economy. Sheep meat and wool are consumed domestically but most is exported to various parts of the world. The industry faces challenges in animal health, with several infectious and non-infectious diseases caused by bacteria, viruses, fungi and parasites, some causing huge annual economic losses.

In Western Australia, especially in the winter rainfall zone, the sheep suffer from diarrhoea caused by gastrointestinal worms, of which the most prevalent are *Teladorsagia circumcinta* and *Trichostrongylus colubriformis*. Over the last few decades, Adjunct Professor Johan Greeff of DPIRD has bred Merino sheep that are inherently resistant to the worms and has produced the most resistant flock of Merinos in the world, the Rylington Flock. However, among the resistant animals, a few develop severe diarrhoea even though they only carry a few worms.

This project aims to find molecular and cellular differences, particularly in the immune system, that might explain the resistance to infection, and also why some resistant sheep still have diarrhoea. This study will focus on the transcriptome of the sheep and the parasite, with a view to exploring the roles of microRNA expression in the relationship between sheep and parasite.

For the sheep transcriptome work, RNA will be extracted from samples of the Rylington Flock. Progress has been slow because good quality RNA has been difficult to extract. However, once this is achieved, proceeding with sequencing and data analysis should be relatively straightforward because there is large database of genomic information for sheep.

For the microRNA of parasites, on the other hand, there was a need to start from scratch by assembling the genome of *Teladorsagia* and *Trichostrongylus*. This meant collecting a large number of parasites, identifying them, then extracting and sequencing their DNA. Currently, the process of assembling the genomes for both worm species is underway.

This research is supported by SAgE; DPIRD; and AWI.

12: Loading MinIon flow cell for Nanopore sequencing of parasite DNA.

3

Water for Food Production

Theme Leaders

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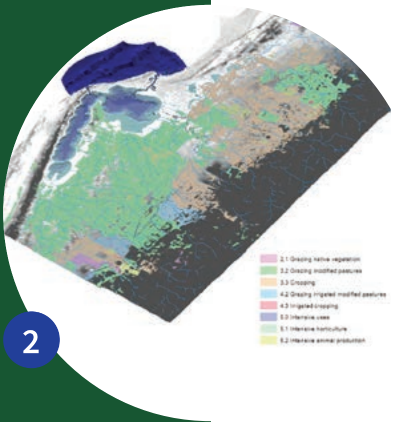
The Water for Food Production theme focuses on improved efficiencies in both dryland and irrigated agriculture, and on better use of finite water resources to meet the food needs of an increasing world population. Thirty-seven per cent of the world's total land area is available for agricultural production, approximately twenty per cent of which is irrigated. Irrigated agriculture provides forty per cent of the world's food and can give crop yields two to four times greater than 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.



Mapping moisture in Variable-Textured Soils of the Western Australian Wheatbelt by Non-invasive Methods

Project team: Assistant Professor Matthias Leopold (leader; matthias.leopold@uwa.edu.au), Dr Ken Flower, Hira Shaukat

Collaborating organisations: UWA; Dr Phil Ward, CSIRO; Dr Craig A Scanlan, DPIRD

Western Australia (WA) has highly variable rainfall. Rapid and precise quantification of hydrological processes in crop fields have always been challenging in farming, because of the variability in soil moisture, which is dependent on the interacting soil properties. The conventional method of extensive core sampling is not time or cost effective, especially in the broadacre cropping systems of Western Australia. Recent advances in geophysical techniques have created an opportunity to determine soil moisture content with high-resolution and minimal soil intrusion. However, these methodologies have mainly been validated for homogenous soils. Currently they do not allow for wide-scale, accurate, predictions of soil moisture in variable-textured soils. Therefore, the aim of this study is to measure moisture in variable-textured soils using geophysical techniques and to understand the dynamics and interacting factors affecting soil moisture content.

Use of electromagnetic induction (EMI) instruments to map soil properties through apparent electrical conductivity (ECa) is gaining importance because the method is economical, mobile and allows for the measurement of relatively large areas in a comparably short time. Therefore, soil mapping is planned using Dualem-1HS for mapping ECa, coupled with Ground Penetrating Radar (GPR), and Electrical Resistivity Tomography (ERT), and relating their evaluations to soil water measurements in different textured soils. Combinations of EMI, GPR, ERT and initial physical assessments/cores to ground truth and calibrate the data, can provide novel, detailed, mapping of soil moisture in variable broadacre cropping sties.

The resulting soil moisture maps will be valuable for farmers to use as the basis for varying crop inputs in precision cropping systems and to predict crop yield potential, using biophysical models like the Agricultural Production Systems Simulator (APSIM).

This PhD project is at methodology development stage. The research has been initiated using combination of EMI, ERT, GPR and initial physical assessment/cores for detailed mapping of soil moisture at number of sites with different soil characteristics in the Wheatbelt. The overall objective is to develop a rapid and cost effective way of measuring and mapping soil moisture in broadacre fields of WA. If successful, this research will provide farmers with crucial soil moisture information to make informed crop management decisions.

This research is supported by SAgE; and GRS for international travel.

1: Measuring and mapping soil moisture in a broadacre field.

Nutrient management benefits to downstream waterways — the Peel-Harvey catchment-estuary system in WA.

Project team: Associate Professor Matthew Hipsey[1] (matt.hipsey@uwa.edu.au), Dr Peisheng Huang[1], Dr Fiona Valesini[2], Karl Henning[3]

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

How will changing land and water management practices on farms benefit downstream rivers and estuaries? Of course, we accept that we need to do our best at the farm-scale to prevent degradation of some of our most prized environmental assets, such as the Peel-Harvey lagoon, Swan-Canning estuary, or Vasse-Wonnerup in southwest WA. Many people would remember the eutrophic conditions and noxious blooms that existed in the Peel Harvey, for example, during the 80's and 90's, prior to the Dawesville Cut construction. Significant efforts in soil testing, nutrient management and restoration initiatives have all made a significant impact in reducing nutrient loads to our waterways, allowing them to remain vital resources for supporting recreation and biodiversity.

But our catchments and waterways are not static. Changes to land use, water resource use, farming practices and climate change have all meant that river flows, water quality and estuary health are constantly changing. A new generation of modelling tools is being developed to help us understand how we can maximise farm exports whilst maintaining healthy waterways. Through development of start-of-the-art catchment and estuary models and landscape analysis of nutrient pathways within the Peel-Harvey region, we have been able to identify nutrient load targets to prevent water quality decline, whilst also factoring in the effects of the drying climate trend. The model provides new opportunities for agencies and catchment managers to prioritise policy and management ideas that can benefit farm productivity whilst reducing downstream impacts.

This research is supported by the ARC Linkage scheme, with support from Murdoch University, UWA, Southern Cross University, the Peel Harvey Catchment Council, the City of Mandurah, the Shire of Murray and the WA Department of Premier and Cabinet. Refer to peel.science.uwa.edu.au for more information.

2: Land-use areas feeding into the Peel-Harvey estuary, as depicted with a 3D water quality model mesh used for estuary health assessment.

Thermal sensing for irrigation control

Project team: Adjunct Professor Hamlyn Jones (leader; hamlyn.jones@uwa.edu.au), Dr David Deery, Dr Hiz Jamali, Ms Tracy May, Dr Paul Hutchinson

Collaborating organisations: UWA; CSIRO Agriculture and Food; Hussat Pty Ltd

One recent aspect of this work has been the development of methods for scheduling irrigation, based on thermal imaging for detection of water stress. More recently, with colleagues in CSIRO Agriculture and Food (Canberra and Narrabri) and with an instrument maker (Hussat) in Griffith, networks of simple field thermal sensors produced by CSIRO (ArduCrop®) as tools for continuous monitoring of evaporation and stomatal conductance for field crops have been developed. A particular innovation for this project has been the incorporation of sensors that record the temperature of dry reference surfaces intended to mimic the expected temperature of a non-transpiring canopy. Such networks can potentially be of use both for irrigation scheduling and for crop phenotyping when large numbers of sensors are deployed. The first results of successful tests of these thermal sensing networks in commercial cotton crops (Jones et al. 2018) have now been published. These tests have shown that evapotranspiration and stomatal conductance can be successfully monitored over the growing cycle of a cotton crop using simple infrared sensors of canopy temperature, when combined with basic meteorological data.

Jones HG, Hutchinson PA, May T, Jamali H and Deery DM (2018). A practical method using a network of fixed infrared sensors for estimating crop canopy conductance and evaporation rate. *Biosystems Engineering* 165: 59-69

This research is supported by CSIRO.

3: Two versions of the CSIRO ArduCrop® thermal infrared sensors showing the solar panel required for long-term deployment in the field. The version of the right has been developed specifically for this project and, as well as a downward-pointing infrared sensor for recording the canopy temperature, also has an upward-pointing sensor that records the temperature of the green painted dome as a dry reference for calculation of evaporation rates. Photo: Hamlyn Jones.

Determination of design criteria to enhance nutrient removal by vertical flow-through wetlands

Project team: Dr Rasha Al-Saedi (leader; 21456205@student.uwa.edu.au), Adjunct Professor Keith Smettem, Hackett Professor Kadambot Siddique

Constructed wetlands are promising ecologically engineered systems for wastewater treatment. Nitrogen removal is of particular concern due to negative impacts on the receiving water bodies. This study assessed: (1) nitrogen removal efficiencies and pathways and the related microbial communities under saturated/unsaturated conditions; (2) nitrogen removal under saturated conditions with enhanced substrate conditions for denitrifying bacteria; and (3) development of clogging within the pore spaces of the inlet filters and filter beds, which is a major operational problem in wetlands.

Chapter One introduces wetlands as a green technology for wastewater treatment and summarizes the current knowledge, theory and background about the design and operational parameters that influence wetland performance.

Chapter Two examines differences between saturated and unsaturated zones in terms of nitrogen removal and the related microbial communities coating the filter bed in a laboratory-scale vertical flow (VFCW) constructed wetland under an influent inorganic nitrogen concentration of 508 mg/L and initial hydraulic loading rate of 1.5 m3/m2.d.

Chapter Three investigates enhanced denitrification in a laboratory-scale VFCW under completely saturated conditions, using two organic carbon additives, along with control columns (without C additives) under an initial hydraulic loading rate of 0.508 m3/m2.d. The investigation also included adding amendments of activated sludge (as another highlighted approach to enhancing denitrification) to the same columns treated with, and without, carbon sources.

Chapter Four investigates whether clogging is enhanced after adding two readily biodegradable organic substrates, sucrose as a sugar source and ethanol as an alcohol source. These treatments were compared to synthetic wastewater without any added carbon source and a tap water control.

In summary, operating a fully saturated zone is an effective and economical option as the observed rate declines in nitrogen concentration were similar in the saturated and unsaturated zones, with the difference in water content between zones accounting for a major difference in mass removal per unit volume of wetland. Attempts to enhance the fully saturated VFCWs by substrate manipulation showed that ethanol positively affected nitrate removal in the absence of activated sludge, but the effect was masked when activated sludge was added to the ethanol treatment. Plate clogging at the inlet area had a major impact on declining outflow rates over time, with additional reduction from microbial clogging of voids in the sand substrate. Investigation into the effect of the design and operation parameters of VFCWs on nitrogen removal is strongly recommended. Attention should be paid to designing systems that reduce inlet filter clogging.

This research is supported by the Iraqi Government's Higher Committee for Education Development Scholarship; the UWA School of Civil, Environment, and Mining Engineering; and IOA.

IOA active in World Water Education

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

In 2018, IOA Adjunct Professors Susana Neto and Jeff Camkin delivered water education and flew the IOA flag around the world.

Nine students from Bhutan, Myanmar, the United Arab Emirates, France, USA, New Zealand, Peru and Australia visited UWA in December 2018 for the Water, Agricultural Landscapes and Food Security course as part of the Brisbane-based International Water Centre's (IWC) Master in Integrated Water Management. Led by Professor Camkin and Professor Neto, the week-long intensive course included guest lectures and field trips supported by IOA members and affiliates Kadambot Siddique, Ed Barrett-Lennard, Ken Flower, Graeme Martin and John Ruprecht. Field trips to the UWA/WA No Tillage Association field trials in Cunderdin and the Gnangara Mound irrigation areas were a feature of the course, as were a serious of interactive workshops aimed at developing shared learning between all participants, guest lecturers and course coordinators.

Enhancing Effective Governance in Transboundary Water Resource Management and Development was focus of another programme delivered by Professor Neto and Professor Camkin in Sydney in May 2018 for the International Centre for Water Resource Management (ICE WaRM) that is based in Adelaide. Applying a similar approach, framed around the personal learning objectives of each participant, the course helped prepare 15 farmers, water resource managers and policy makers from the Indian states of Andhra Pradesh and Telangana for the challenges of managing shared water between these recently bifurcated states.

In October Professor Camkin was part of a South Australian water mission to Nanjing, China, which delivered a pilot Capacity Development Programme on River Basin Planning involving ICEWaRM and Hohai University, China.

Professor Camkin and Professor Neto are also flying the IOA flag in Europe, where they are based. Each year they deliver a course on Water Governance and Integrated Water Management in Germany for international students as part of the University of Darmstadt's MSc in Tropical Hydrogeology and Environmental Engineering, and are collaborating with the University of Algarve, Portugal, on water research.

At another level of activity, and to further support global capacity building in water management, Professor Camkin and Professor Neto are Editors-in-Chief of New Water Policy and Practice Journal, which they founded in 2013. Supported by Policy Studies Organisation in Washington D.C, USA, the journal aims to provide a platform for the world's emerging water leaders and thinkers. The journal will be published through Wiley-Blackwell from 2019.

Professor Neto, a senior researcher with the University of Lisbon, was elected President of the Portuguese Water Resources Association (APRH) in April 2018, this Association is also coordinating the national governing member in the International Water Association (IWA) until June/July 2020. APRH is currently involved in a massive programme raising awareness of water conservancy and sustainability within the context of global climate change.

4

Food Quality and Human Health

Theme leaders

Professor Trevor Mori
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Health attributes of foods is 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.

Development and health evaluation of nutritionally enhanced apples

Project team: Professor Jonathan Hodgson (leader; Jonathan.Hodgson@ecu.edu.au), Dr Michael Considine, Professor Tim Mazzarol, Dr Catherine Bondonno, Professor Kevin Croft, Professor Wallace Cowling, Dr Elena Mamouni Limnios, Dr Nicola Bondonno, Diana Fisher, Fucheng Shan, Kevin Lacey, Steele Jacob

Collaborating organisations: UWA; School of Medical and Health Sciences, Edith Cowan University; DPIRD; Australian National Apple Breeding Program; Pome West; Horticulture Innovation Australia; Fruit West

This program of research and development is aimed at transforming the value of Australian-bred apples. The goal is to gather evidence to support the development, production and consumption of newly released apple varieties with elite levels of flavonoids. Our hypothesis is that particular flavonoids present at high levels in some apples contribute significantly to the nutritional quality of fresh apples. Flavonoids are compounds present in plant foods, some of which are likely to provide a positive contribution to the health of the vascular system. The flavonoid contents of apples vary by several orders of magnitude between varieties. Previously, industry attention has been gained by demonstrating the significant health benefits of a flavonoid-rich apple.

Key findings of the research program so far include:

1. Higher intakes of apples, and a major flavonoid found in apples (quercetin), is associated with lower risk of cardiovascular and all-cause mortality.
2. Market surveys and conduit analysis of over 700 consumers show that the perceived nutritional qualities of an apple is a major driver of purchase decisions.
3. There is a high degree of variation in flavonoid/quercetin content of Australian apples.
4. The flavonoids present in cold-stored apples are stable over >6 months.
5. The Cripps Pink (Pink LadyTM) variety was identified as an apple with one of the highest flavonoid/quercetin levels.
6. Short-term and regular consumption of Cripps Pink apples result in improved blood vessel function (a measure related to cardiovascular health) in healthy individuals.
7. A new Australian-bred apple (BravoTM – developed by the Australian National Apple Breeding Program) was identified as being a good source of flavonoids/quercetin. As this apple also has very desirable qualities in terms of taste, crispness and aesthetics, it has the potential to be a great source of export income for Australia.

During 2018, progress has been made on evaluating the health effects of regular consumption of the new BravoTM apple. Late 2017 funding was sought and obtained from FruitWest and Edith Cowan University to conduct a trial to investigate the short-term effects of regular consumption of BravoTM apples. The trial, with 30 participants, was conducted during 2018. Results are currently being analysed and it is expected that they will be published by late 2019. The trial will establish if the regular consumption of one BravoTM apple each day can improve measures of vascular health.

This research is supported by Australian National Apple Breeding Program; DPIRD; Horticulture Innovation Australia; Pome West; and Fruit West.

1: An apple a day really does keep the doctor away.

Modelling fruit composition within the grapevine canopy

Project team: Dr Joanne Wisdom (leader; joanne.wisdom@uwa.edu.au), Emeritus Professor John Considine, Professor Michael Considine, Associate Professor Megan Ryan

Collaborating organisations: UWA; ARC; Evans and Tate; Australian Grape and Wine

Universally, wine quality is determined by attributes of the fruit at harvest. The composition and physical parameters of a grape berry vary greatly within- and between-vines. However, it is challenging to measure these accurately in field settings. This research focused on Cabernet Sauvignon grown in Margaret River, and demonstrated that berry mass is a primary, within-vine, determinant of composition, regardless of, but influenced by whole vine biomass. An alternative pathway for metabolite translocation was proposed. A new, hierarchical sampling protocol was also presented, which enables precise and repeatable estimation of a parameter of interest, in the field, for a given budget.

This research is supported by RTP Scholarship, the Australian Research Council (LP034319) in a collaborative fund with cash and in-kind support from Evans & Tate Ltd and The University of Western Australia and cash from the Australian Grape and Wine Council Project.

2: *Vitis vinifera* L. cv. Cabernet Sauvignon in Margaret River.

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

Project team: Dr Natalie Ward (leader; natalie.ward@uwa.edu.au), Professor Jonathan Hodgson, Professor Trevor Mori, Associate Professor Stuart Johnson, Dr Carolyn Williams, Associate Professor Seng Khee Gan, Professor Lawrence Beilin

Collaborating organisations: UWA; Royal Perth Hospital Medical Research Foundation; Curtin University, School of Public Health; Edith Cowan University, School of Medical and Health Sciences; Sanitarium Health and Wellbeing Company; Il Granino Bakery; Otaway Pasta Company

Type 2 diabetes may affect as many as 3.5 million Australians. Although there is a strong genetic link, diet and lifestyle also play important roles in the development of type 2 diabetes. Early management of type 2 diabetes through diet and lifestyle change can help to maintain blood glucose levels within normal ranges, as well as beneficially impact 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 that is rich in fibre and protein and contains negligible sugar and starch (glycaemic carbohydrate). There is growing evidence that foods containing lupin could make a positive contribution towards the management of type 2 diabetes via their low glycaemic index.

This project is 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 is 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 is to determine whether regular consumption of lupin-containing food products can improve short-term glycaemic control and lower blood pressure in type 2 diabetic participants. Secondary aims are to determine whether regular consumption of lupin-containing food products can improve cognitive domains of attention and working memory in type 2 diabetic participants.

In 2018, analysis of the primary endpoint results was completed. This included batch analysis of stored blood samples, input and analysis of food frequency questionnaires, input of the home blood pressure and home glucose monitoring data and subsequent analysis, and discussions with statisticians on the interpretation of results. In early 2019, discussion with the statisticians is ongoing, with the final results expected to be written up and submitted for presentation by mid-2019.

Further analysis of cognition data is expected in 2019, as well as any required revisions of other endpoints/analysis.

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

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, and enabling us to respond efficiently to new challenges and opportunities as they arise. A recognisable and identifiable agricultural engineering theme presents extensive opportunities for collaboration between farmers and agricultural machinery manufacturers with the IOA in order to undertake research and development (R&D) focused on bringing about commercial innovation.

Profitable and environmentally sustainable sub clover and medic seed harvesting

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

This project comprises of a team with skills in agricultural engineering, pasture agronomy and breeding and plant physiology. The research team will work with a range of leading seed growers and pasture seed companies in WA, SA, NSW and Victoria to develop innovative solutions to increase subterranean clover and annual medic seed harvesting efficiency and reduce environmental impacts. The ideas and experiences of seed growers and agronomists will be captured in an initial workshop to refine project directions and identify key collaborators. The aim is to develop solutions that can be adopted on different soil types across the main seed growing regions. The project will mainly focus on subterranean clover, as it has the largest seed industry, but many principles will also apply to annual medics.

The project commenced in late 2018 and appointed project staff as well as a PhD candidate. Preparations were made for an intensive start to 2019, with field visits and seed growers workshops being planned in WA, SA and NSW in the early part of the year.

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

1: The project team inspecting sub clover burr with a seed producer prior to harvest.

On-farm automatic sheep breed classification using deep learning

Project team: Sanabel Abu Jwade[1], Dr Andrew Guzzomi[1] (andrew.guzzomi@uwa.edu.au), Professor Ajmal Mian[1]

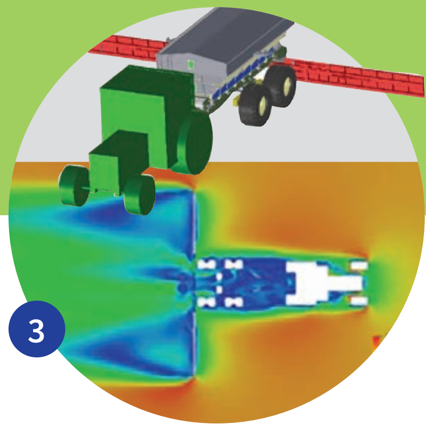
Collaborating organisations: Kingston Rest, UWA[1]

It is well established that the amount of meat produced from a sheep depends on its breed. Therefore, accounting for different breeds can assist in accurate estimation of meat production. Autonomous methods that can replicate the identification of a sheep breed expert and can achieve the requirements in a farm environment are beneficial to the industry.

This project investigated the potential to use deep learning to accurately and quickly identify sheep breeds during the drafting process. Three main contributions were made: a) a prototype computer vision system in a sheep farm was developed, b) a database compromising four breeds totalling 6,570 sheep images captured on farm were labelled c) a sheep breed classifier was trained using machine learning and computer vision to achieve accuracy of 95.8% with 1.7 standard deviation.

This classifier could assist sheep meat producers as a tool to accurately and efficiently differentiate between breeds and allow more accurate estimation of meat yield and cost management.

This research was supported by a DPIRD SIBI scholarship.



Weed Chipper: Site specific weed control for large-scale cropping

Project team: Dr Andrew Guzzomi[1] (andrew.guzzomi@uwa.edu.au), Dr Carlo Peressini[1], Dr Michael Widderick[3], Dr Adam McKiernan[3], Dr Bhagirath Chauhan[4] and Dr Michael Walsh[2]

Collaborating organisations: UWA[1], USyd[2] QDAF[3], UQ[4]

The targeted tillage "Weed Chipper" has been developed around the simple yet effective modification of a standard cultivator with hydraulic breakout tynes. Instead of the tynes being fully engaged for complete soil tillage the team developed a system which incorporated springs and a modified hydraulic system to maintain the tynes in a standby position above the ground. 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. As well as reducing the reliance on herbicides for fallow weed control the Weed Chipper has great operational flexibility as its use is not restricted by environmental conditions that prevent the use of herbicides (i.e. wind, humidity and high temperatures). The "Weed Chipper" represents the development of an alternative non-chemical weed control technology for Australia's conservation cropping systems.

This research was supported by GRDC.

2: The Weed Chipper in action. Photo: Anvil Media.

Understanding the effects of air flow on Fertiliser Distribution

Project team: Andrew Guzzomi[1] (andrew.guzzomi@uwa.edu.au), Dr Carlo Peressini[1] and Dylan Channon[1]

Collaborating organisations: UWA[1], Roesners

The Marshall Multispread is an all-purpose fertiliser spreader designed and manufactured in Harvey, WA by Roesner Pty Ltd. The Marshall Multispread is used by Australian farmers to apply granulated fertilisers such as urea and superphosphate, as well soil ameliorants like lime, gypsum, dolomite and manure. Since the early 1980s, over 10000 Multispread units have been manufactured and today the Multispread range is used in all forms of Agriculture, from large scale cropping through to livestock and horticulture. Roesner Pty Ltd has developed 'lime' curtains to increase spread width.

The UWA Agricultural Engineering team worked with Roesner Pty Ltd to combine computational fluid dynamics (CFD) modelling techniques and wind tunnel testing approaches to investigate the performance of curtain design on fertiliser spread. The outcomes of the research are leading to improved curtain design and spreader performance.

This research was supported by Roesners and AusIndustry through an Innovation Connections Grant.

3: Spreader with curtain (a) and CFD simulation results (b).
Image: Dylan Channon

Underground wireless sensor networks for distributed soil moisture and temperature monitoring

Project team: Assistant Professor Matthias Leopold, Associate Professor Rachel Cardell-Oliver (leader; rachel.cardell-oliver@uwa.edu.au), Professor Christof Huebner

Collaborating organisations: UWA, Mannheim University of Applied Sciences Germany (and UWA Adjunct)

A wireless sensor system has been developed, installed on the UWA farm and in continuous operation since September 2018. A challenge is the need for an underground radio technology since heavy machinery will pass through the agricultural fields and therefore only a few above-ground stations acting as gateways are acceptable. Our sensor stations use LoRa (long range) radio technology operating in the frequency range 174 MHz and placed underground at depths of 20 to 50 cm. We have so far collected 10 months of distributed soil moisture and temperature data on the farm, as well as measurements of the radio performance.

4: PA wireless sensor system has been developed and installed on the UWA Farm.

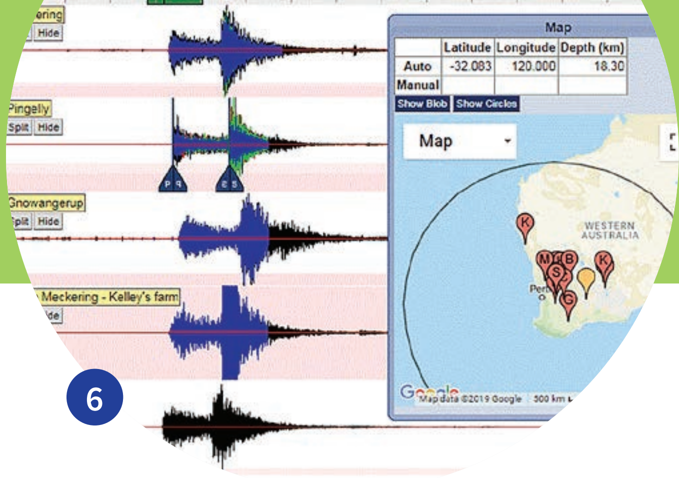
Portable multispectral/ hyperspectral sensors for crop management

Project team: Professor Dilusha Silva (dilusha.silva@uwa.edu.au), Associate Professor Jarek Antoszewski, Associate Professor Mariusz Martyniuk, Associate Professor Gino Putrino, and Professor Lorenzo Faraone

Collaborating organisations: UWA

This is an on-going project, funded over the years by multiple organizations, including GRDC, multiple defence organizations (US and Australian), and the Australian Research Council. The 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. Preliminary optical modules were demonstrated in 2018, which are now being further developed to enhance the spectral behaviour characteristics for on-farm applications.

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



Sensors for fly-strike detection

Project team: Professor Dilusha Silva (dilusha.silva@uwa.edu.au), Associate Professor Gino Putrino

Collaborating organisations: UWA, DPIRD

Cutaneous myiasis, commonly known as 'flystrike' is the invasion of a sheep's body by parasitic flies and maggots, which eat away at the flesh of the sheep. In Australia, about 90% of strikes are due to Australian sheep blowfly (*Lucilia cuprina*). Starting with two internships funded by DPIRD in 2018, the project reviewed and assessed various sensing technologies for detecting flystrike on sheep. Technologies assessed included infrared imaging, and chemical odour sensing. Based on these studies, the project is now exploring and developing sensors in an optimal configuration for assessing sheep on-farm.

Earthquake monitoring in the WA wheatbelt

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

Collaborating organisations: UWA

The seismograph at Ridgefield recorded some of the aftershocks of the September 2018 Mag 5.7 earthquake west of Mount Barker. The data from Ridgefield, plus other stations Vic Dent operates, have assisted in the more-accurate relocation of many wheat belt seismic events, and these data are forwarded to the International Seismological Centre in Reading, UK. This data was shared in two presentations at the 2018 Australian Earthquake Engineering Society (AEES) conference in Perth, and will form part of a publication being prepared for the 2019 AEES conference.

6: The Mag 6.6 earthquake near Broome on 14 July 2019 as recorded on some of the stations in the network Vic Dent operates. The Ridgefield data is shown (as "Pingelly") and the map shows the estimated distance of the earthquake from Ridgefield, using the time difference of the compressional and shear waves.

6

Agribusiness Ecosystems

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

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

The aim of the Agribusiness Ecosystem theme at the UWA Institute of Agriculture is to advance scholarship on socio and economic issues affecting agriculture locally in Western Australia, at 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 2018. Our research focus contributes to realisation of the 2030 Agenda of Sustainable Development.

1

2

Investigating the impacts of public food safety certification to farm performance on small-scale farmers. A case study of IndoGAP implementation on shrimp farming in Indonesia

Project team: Miss Maharani Yulisti (PhD candidate; maharani.yulisti@research.uwa.edu.au), Dr. Amin Mugera and Dr. James Fogarty

Collaborating organisations: UWA

This project analyzed the impacts of the adoption and implmentaion of Indonesian Good Aquaculture Practice (IndoGAP) on the perfomance of smallholder shrimp farms in Indonesia. Since most shrimp is farmed with fish, the outcomes of interest were shrimp and fish production, total revenue, variable costs and net profit. Preliminary results indicate adoption of IndoGAP is positively influnced by age and education level of farmer, pond size, access ot credit and trainning. Implentation of IndoGAP certification is positively associated with associated with improved shrimp yield and decrease variable costs and negatively associated with fish yield and total revenue.

This project is supported by the Australian Award Scholarship (AAS) and School of Agricultural and Resource Economics UWA.

1: Researcher and her interviewees (feed agent, collector, farmers, and lecturer) in a shrimp pond.

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

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

Collaborating organisations: UWA; Honey for Life; Boathaugh Estate

Commercial and semi-commercial beekeepers in Australia and internationally are returning to stationary beekeeping. This move comes as suitable habitat for honey bees (*Apis mellifera*) declines, the cost of transport increases and we face concerns regarding the impact of hive migration on honey bee health and pest and disease transfer.

Restoring lands with the right mix of high-value, high-yielding melliferous flora can create productive year-round stationary enterprises. However, designing year-round high-value honey production sites is made difficult by a lack of guidelines and tools.

This project will create models that can be used by apiarists to predict the productivity of a hive site. Predictions will be made based on the species of flora present and the distribution of the flora across the site. Models will inform decisions regarding optimal locations for hives, optimal timing of movement of hives between locations and flora enrichment to improve site productivity and honey quality. The project will also account for temporal variation in flowering, nectar and pollen production, as well as bee colony population dynamics. Spatial factors such as plant location, density, patchiness and bee foraging preferences may also be included. Predictive models will be validated through monitoring hive production and bee movement amongst local flora at case study sites. Methods for designing optimal year-round flowering sites in Australia will be developed, based on these models.

This project aims to: (i) identify the requirements for methods to help design year-round, high-value honey production sites and systems; (ii) develop a non-spatial model predicting honey production for a stationary hive, based on the surrounding flora; (iii) develop a model that includes spatial aspects of bee foraging; and (iv) develop a method for optimising planting designs for year-round high-value honey production at stationary hive sites.

In September 2018, research and data collection for this project began and the CRCHBP officially opened at the Yanchep training and business hub; representatives from the project team had the opportunity to attend the launch. In October 2018, ABC Rural Radio visited UWA and the Centre for Integrative Bee Research (CIBER) and representatives from the project team had the opportunity to attend the recordings.

This research is supported by CRCHBP.

2: A wide range of plant species will be considered for the planting designs. Photo: Joanne Picknoll.

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

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

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

Agriculture in southern Bangladesh centres 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 is 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 current situation, BAU is to understand the context for practice change in dry season cropping in Southern Bangladesh, BAU is undertaking a baseline survey of 500 households in both saline and saline-free areas, while ARF is conducting focus group discussions to identify the limitations to dry-season cropping.

To understand/evaluate production technologies for dry season cropping of pulses in saline-free land to increase productivity and profitability, BARI undertook agronomic research in Southern Bangladesh during 2017/18. A series of agronomic management trials was initiated: The sowing date of 15-30 January was found preferable to later sowing in mungbean, and line sowing by machine both yielded more than sowing by hand-broadcast and facilitated weeding. An IPM package to manage thrips and pod borers comprising blue sticky traps and synthetic insecticides was promising.

These experiments on mungbean will be repeated. A series of 14 demonstrations of a mungbean production package were conducted on one hectare plots involving several farmers. The average productivity of the production package was 1372 kg/ha compared to 954 kg/ha achieved on adjacent farmer-managed plots, indicating a yield gap of 418 kg/ha and a yield advantage of 44%.

To identify wheat germplasm with salinity tolerance adapted to Southern Bangladesh, a set of wheat lines was established to benchmark wheat germplasm. This benchmark set was evaluated at a total of 10 field trials in southern Bangladesh. The distribution of soil salinity was mapped within sites and over time. Soil salinity levels were typically 2 – 3 times higher at anthesis compared to sowing. There was a strong negative correlation between mean soil salinity and site mean grain yield across those trials with detailed soil salinity characterisation. Rankings of wheat lines for yield at the four trial sites with the highest levels salinity were reasonably consistent based on unadjusted means. In parallel, the salt tolerance *Nax* gene from Australia has been introgressed in varieties BARI Gom 25 and 26. We expect to start testing the products in 2019.

To identify germplasm of pulses and forages with tolerance to salinity and water-logging stress, we developed screening protocols for water-logging tolerance at germination in water-logged soil in lentil, pea and mung bean at UWA with post-graduate students and extended the methods to enable specific seed germination in anoxia.

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

3: Farmer in Barisal Division, Bangladesh discusses mung bean disease symptoms with Dr Mahbub Alum (Bangladesh Agricultural Research Institute -Left) and Dr Eric Huttner (Australian Centre for International Agriculture Research).

4

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

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

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

The project aims is to improve agricultural productivity and profitability in pilot communities in East Timor by addressing technical and social impediments to annual crop intensifications, 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 Vison 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.

To develop intensive irrigated cropping systems, we researched cropping after rice. Eight agronomic trials involving mungbean, soybean, sweet corn/maize, tomato and chili pepper were conducted as UNTL Honours research projects on fertilizer responses on land previously cropped with paddy rice using low inputs. Treatments examined were combinations of rice hull biochar, superphosphate and cow manure. There were strong positive responses to rice hull biochar and superphosphate in every experiment and the average yield increase from biochar was >200%, increasing yield from 1.0 t/ha to 3.6 t/ha across all crops. Both rice hull biochar and superphosphate increased yields dramatically in the infertile Vemasse soil. We are further evaluating the direct effects and residual effects of biochar on rice in the wet season.

Common beans are a lucrative crop in upland Timor Leste, but lowland production is limited by temperatures above 30 °C. A June/July temperature window for bean production in the lowlands was investigated in a trial of sowing dates (June-July) x genotypes (7) at two South coast sites by MAF. June planting in Betano gave bean yields above 1 t/ha. This is the first time common beans have been shown to grow and yield on the south coast.

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. Four months after planting sandalwood tree survival rate was 79%. Although early sapling growth varied over sites the fertilizer treatment effect was non-significant.

Training was an important AI-Com activity focusing on MAF research staff and UNTL students with a total of 256 days of training given, of which 31% were with women. Additionally, cooperation with UNTL has linked project agronomic implementation to student capacity building through 21 Honours student research projects in 2017/18.

This project is supported by an ACIAR grant.

4: Mr. Luis Almeida of ACIAR-funded Ai-Com project shows a recently planted sandalwood seedling in Natarbora, Timor-Leste.

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

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

Since 2014, CERU has undertaken the foundation research for the Business Council of Co-operatives and Mutuals (BCCM), National Mutual Economy Report each year. 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 base line 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 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 has been recognised by the International Co-operative Alliance (ICA) as global best practice.

This research is supported by BCCM.

Co-operative Federation of WA Centenary History

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

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

This project 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.

This research is 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.

ANZAM Special Interest Group

Project team: Winthrop Professor Tim Mazzarol (leader; tim.mazzarol@uwa.edu.au), Professor Delwyn Clark, Professor Sophie Reboud

CERU has led the development of a Special Interest Group, within the Australian and New Zealand Academy of Management (ANZAM). During the annual ANZAM conference, held in Auckland (5-7 December 2018), a series of events and workshops were held. This included an industry workshop coordinated by University of Waikato and involved industry representatives from the national co-operative federation NZ Co-op, and Capricorn Society Ltd, a leading cooperative enterprise in the auto trades sector.

This research is supported by Australia and New Zealand Academy of Management (ANZAM); Co-operative Federation of New Zealand (NZCoop); and Waikato Business School, University of Waikato.

Co-operative and Mutual Strategic Development Program

Project team: Winthrop Professor Tim Mazzarol (leader; tim.mazzarol@uwa.edu.au), Dr Steve Brown

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 cooperative and mutual enterprises. This program has attracted strong interest from across Australia and internationally.

During 2018 the program was run as follows:

- 7-9 January: in Melbourne with a strong participation from CMEs across the east coast.
- 15-15 February: in Albany for the Stirlings to Coast farmer organisation who were working towards the foundation of a new co-operative. Since then this new enterprise has been founded.
- 25-18 March: in Lismore in conjunction with the University of New England. This program attracted around 24 directors and managers from a wide-cross section of co-operative and mutual enterprises across eastern Australia.
- 23-15 June: in Perth with a range of local WA co-operatives and mutual firms attending, including some from the eastern states.
- 15 November: presentation at the Annual BCCM conference in Adelaide on the program.
- 30 October to 1 November: in Perth for a visiting delegation of co-operatives from Malaysia. This is the second year that Malaysian co-operatives have come to Perth to undertake this program.

This research is supported by AIM WA – UWA Business School Executive Education; Co-operative Bulk Handling Ltd; Co-operatives Federation of WA (Co-op WA); Capricorn Society Ltd.; iCoops Malaysia.

Factors Influencing Member Value in Agricultural Co-operatives in Vietnam

Project team: Pham Trung Tuan (PhD candidate), Winthrop Professor Tim Mazzarol[1] (leader; tim.mazzarol@uwa.edu.au), Dr Elena Mamouni-Limnios

This thesis examines the agricultural co-operative sector in Vietnam, within the context of moving from a centrally planned economy to a market-oriented system. This research used a qualitative methodology. Although co-operative development and promotion have enjoyed the support of the Vietnamese Government and other stakeholders, various internal and external inhibitors have acted to constrain the progress and optimization of opportunities that co-operatives present, especially in terms of management capacity, political intervention, member participation, credit service, and marketing service provision. Recommendations are made aimed at improving Vietnam's co-operatives' ability to create and sustain value-adding activities for the members.

This research is supported by AusAid Scholarship.

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

Project team: Dr Thakur Prasad Tiwari (leader; T.Tiwari@cgiar.org), Dr Fay Rola-Rubzen, Dr Roy Murray-Prior, Dr Ram Datt, Dr Kalyan K Das, Surya Adhikari, Md Mamunur Rashid, Dr Mazharul Anwar, Santosh Joshi, and Amal Roy

Collaborating organisations: UWA; CIMMYT; Bihar Agricultural University; Uttar Banga Krishi Viswavidyalaya; Nepal Agricultural Research Council; Rangpur-Dinajpur Rural Services Bangladesh; Bangladesh Agricultural Research Institute; Dreamwork Solution; Satmile Satish Club O Pathagar

South Asia accounts for two-thirds of the world's absolute poor. One of the strategies to alleviate the poverty situation, particularly in farming communities in the Eastern Gangetic Plains of South Asia, is through sustainable and resilient farming systems intensification (SRFSI). The aim of the SRFSI project is to reduce poverty in the Eastern Gangetic Plains by improving productivity, profitability and sustainability of small farmers while safeguarding the environment. The scaling project is the final phase of the SRFSI project (2014-2019). In particular, the socio-economic and gender components aim to understand the socio-economic impacts of conservation agriculture technologies among men and women farmers in the Eastern Gangetic Plains of South Asia.

A survey participated by 1,780 men and women farmers was conducted in 2018 across Nepal, India, and Bangladesh. In terms of capacity development, about 85 research partners including academics, development workers, and postgraduate students were trained on farm economic analysis in November 2018 including 29 participants from Nepal Agricultural Research Council in Kathmandu, Nepal, 33 participants from Bihar Agricultural University in Bihar, India, and 23 participants from Uttar Banga Krishi Viswavidyalaya university in West Bengal, India.

In terms of gender monitoring, the fourth report (2018/19) is composed of 19,167 project participants across all SRFSI activities in all project research sites, of which 64% were participated by either female-only or joint participation of both male and female.

A paper on identifying determinants in popularising conservation agriculture sustainable intensification in Coochbehar, West Bengal, India was presented during the 63rd AARES Annual Conference in Melbourne on 12-15 February 2019.

This research is supported by ACIAR and managed by CIMMYT.

5: Monitoring and evaluation field visit among women farmers in West Bengal, India. Photo: SRFSI, 2018.

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

Project team: Associate Professor Fay Rola-Rubzen (leader; Fay.Rola-Rubzen@uwa.edu.au), Dr Kalyan K. Das, Dr Ram Datt, Dr Yuga Nath Ghimire, Dr Md Farid Uddin Khan, Md Mamunur Rashid, Dr Roy Murray-Prior, Dr Renato Villano, Jon Marx Sarmiento

Collaborating organisations: UWA; Bihar Agricultural University; Uttar Banga Krishi Viswavidyalaya; Nepal Agricultural Research Council; Rangpur-Dinajpur Rural Services Bangladesh; Rajshahi University; University of New England

South Asia remains to have one of the highest concentration of poverty in the world, and India, Bangladesh, and Nepal accountfor the highest poverty incidence in the region. In the Eastern Gangetic Plains of South Asia, various development projects were implemented to improve the productivity, profitability and sustainability of small farmers but the success rates vary. Often, there is low adoption of improved technology outside the project sites. Neo-classical economic theory alone cannot explain why farmers are not adopting even if interventions seem to be in their best interest. Thus, a better approach is needed to understand farmer behaviour. This project examines whether behavioural economics can explain better adoption/ adaptation decisions than conventional adoption models, and if so, how can it be used to “nudge’ farmers to adopt/ adapt conservation agriculture for sustainable intensification technologies?

The Farmer Behaviour Insights Project (FBIP) is one of the pioneering ACIAR projects focussing on the role of behavioural economics in agricultural technology adoption. The inception workshop took place at UWA, Perth on July 2018. Dr Fay Rola-Rubzen and Dr Roy Murray-Prior conducted training on behavioural economics, gender awareness and mainstreaming, and participatory action research in Bangladesh, India, and Nepal from August to October 2018. The project has also completed the literature review on farmer decision-making and technology adoption and farm typologies in South Asia. The research partners were also trained on focus group discussion and key informant interviews in November 2018.

The project has completed 31 focus group discussions (FGDs) across Nepal, India and Bangladesh involving farmers and service providers. The findings from the FGDs were reported during the evaluation and planning workshop in Dhaka on March 2019. Currently, the research partners are conducting the Key Informant Interviews (KIIs), and around 300 KIIs has so far been completed (80%). The design of the survey is underway and is expected to be field-tested and implemented after KII completion. FBIP has also released the inaugural issue of its e-newsletter.

This research is supported by the Australian Centre for International Agricultural Research (ACIAR).

6: Kidney bean field observation and interview in Sunsari, Nepal. Photo: FBIP, 2018.

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

Project team: Bibek Sapkota[1] (leader; bibek.sapkota@research.uwa.edu.au), Dr Maria Fay Rola-Rubzen[1], Dr Michael Burton[1], Dr Roy Murray-Prior[4]

Collaborating organisations: [1]UWA; [2]NARC; [3]ACIAR; [4]Development and Extension Services, North Queensland

Nepalese agriculture is prone to numerous risks stemming from the vagaries of nature and fickle market forces. With the main purpose of assisting smallholder farmers in managing such risks, the Government of Nepal initiated an agriculture insurance program in 2013 employing a public-private-partnership model. However, thus far, farmers' participation, particularly in the crop insurance program, has remained considerably low despite a 75% subsidy in the insurance premium. The uptake of an insurance product is determined by farmers' willingness to pay for it. Faulty design of the insurance products, which does not consider farmers' needs and preferences, has been reported as the major reason for the failure of agriculture insurance programs in many countries. The crop insurance product currently available in the Nepalese market was designed based on a feasibility study which only addressed supply side issues. This study analyses the demand and supply incongruity of agriculture insurance products in Nepal focusing on demand side issues. The study follows a triangulation mixed-methods research design to study farmers' risk perceptions and preferences, risk management strategies, factors affecting risk preferences and management choices, and their willingness to pay for crop insurance. The qualitative study employs in-depth interviews followed by cognitive mapping techniques to analyse the relationships between various constructs related to farming risk. Similarly, the quantitative study employs a household survey coupled with lottery-choice experiment and discrete choice experiment to validate the findings of qualitative study. Risk mapping technique, exploratory factor analysis, logistic regression and conditional logit model will be used to analyse the quantitative data. The findings of this study will be useful for insurance companies and the government of Nepal in designing effective crop insurance products and farm risk management support programs.

In 2018, the qualitative part of the project was completed and an article entitled "Farmers' Risk Perceptions and Preferences: An Application of a Cognitive Mapping Approach".

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 source 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 demand for crop insurance products. 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 bringing out important information required for better farming risk management, we have validated cognitive mapping as an appropriate approach for studying farmers' risk perceptions and management decisions.

Towards the end of 2018 and start of 2019, the fieldwork related to quantitative part of the project was completed. Data entry and preliminary analyses has already been completed. Now, I am writing three additional articles based on the quantitative part of the project. I expect to submit the thesis by the end of August 2020.

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

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

8

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

Project team: Jon Marx Sarmiento (leader; jon.sarmiento@research.uwa.edu.au), Dr Fay Rola-Rubzen, Dr James Fogarty, and Dr Larry N. Digal

Collaborating organisations: UWA; University of the Philippines Mindanao

As many as 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 very poor. Promoting inclusive agricultural development may offer a pathway out of poverty. This thesis evaluates the potential of inclusive agribusiness value chain as a strategy for rural development.

In the first paper, we developed a framework in measuring comparative advantage and applied it to the tropical fruit exports from the Philippines. We calculated the annual comparative advantge performance of leading Philippine tropical fruit exports during the last 20 years, 1997-2016. Findings reveal that the Philippine exports on bananas, prepared and preserved pineapples, fresh and dried pineapples, pineapple juice and prepared and preserved mixed fruits had comparative advantage in the international market. Production performance, yield performance, net returns, land area, net profit-cost ratio and value of production had significant and positive correlation to the comparative advantage performance of the tropical fruits.

In the second paper, we compared the technical efficiency performance of farmers across various types of contract farming: individual contract, cooperative contract, and growers without a contract. We employed both Data Envelopment Analysis-truncated regression with bootstrapping and Stochastic Frontier Production function to calculate the technical efficiency of 187 farmers. We then applied propensity score matching to address the potential self-selection bias. Using both techniques, the results reveal that contract farmers were 28%-33% more efficient than farmers without contract. Access to individual contract is inclined towards medium to large farmers but there is a prospect for smallholder farmers to participate in export value chains through cooperative contract farming arrangement.

In the third paper, we developed an index to measure the capacity of farmers to participate in modern markets. The Modern Market Participation Index has five indicators, which comprise the five capitals of sustainable development—economic, built, human, social, and natural. The index was applied to 264 banana and mango farmers in northern and southern Mindanao. The results suggest that there is a potential for the index to explain modern market participation with 86% accuracy level. Moreover, the farmers supplying in modern markets have higher levels of capitals compared to farmers supplying in traditional markets. While, in general, improving the capitals will increase the likelihood of supplying in the modern markets, some farmers with high capitals prefer the traditional markets due to other factors not captured in the model. Attention is needed to improve the physical, natural, financial, social, and human capitals (in decreasing order of importance) of smallholder farmers to improve the likelihood of participation in the modern markets.

This is a PhD project of Jon Marx Sarmiento, an Australia Awards ACIAR John Allright Fellowship recipient, with support from the University of the Philippines Mindanao.

8: Fresh Cavendish banana harvests of smallholder farmer in Davao del Norte, Philippines. Photo: Sarmiento, 2018.

Investigating the potential of insurance as a mechanism to enhance the performance of risky conservation tenders

Project team: Miss Toto Olita[1] (PhD candidate; toto.olita@research.uwa.edu.au), Prof Steven Schilizzi[1], Dr Md Sayed Iftekhar[1], Prof Uwe Latacz-Lohmann[2], Prof Peter Boxall[3]

Collaborating organisations: [1]UWA; [2]Christian-Albrechts-Universitaet Kiel, Germany; [3]University of Alberta, Canada

In the face of a shrinking budget for environmental programs, it is necessary for the conservation agencies to design and implement mechanisms that meet environmental objectives at a minimum implementation cost. However, in the presence of uncertainties, designing such programs often present challenges to the conservation agencies. For example, landholders can be exposed to high cost variability when delivering environmental goods and services and therefore, may demand additional incentives as compensation for undertaking "risky" conservation projects. In such situations, the conservation agencies may be forced to over-spend public funds to achieve their conservation target, otherwise, if landholders' participation rates are too low, the conservation agencies may not achieve the desired conservation target.

This study contributes to the conservation auction literature by developing an optimal budget allocation model in the presence of an embedded insurance mechanism. We use numerical simulations to investigate whether it is cost effective for the conservation agency to offer insurance subsidies. Simulation results show that, relative to the no insurance scenario which acts as our baseline - the presence of an embedded insurance mechanism increases the overall cost-effectiveness of a target-constrained tender. We also see that, even when the conservation agency subsidises the insurance premium, the reduction in the program's expenditure is, on average, higher than the cost of insurance subsidisation.

Part of this research was presented at the 6th World Congress of Environmental and Resource Economists, held on 25-29 June, 2018, in Gothenburg, Sweden.

This project is supported by the Australian Research Council Discovery Grant Number DP150104219, SIRF and UWA Top-up Scholarship.

Adoption Portfolio of Sustainable Agricultural Intensification Practices on Maize-Legume Farming systems in Kenya: Application of K-Modes Clustering

Project Team: Wilckyster N. Nyarindo[1] (PhD candidate: wilckyster.ogutu@research.uwa.edu.au), Dr Amin Mugera[1], Assoc/Prof Atakelty Hailu[1], and Prof Gideon Obare[2]

Collaborating Organizations: [1]UWA , [2]Egerton University

Rural households in most developing countries comprise of small-scale farmers who depend on agriculture for food and income. However, production in such areas are always conditioned by the underlying factors such as overdependence on rain fed agriculture, poor soil fertility, pest and diseases, lack of implementation capacity due to institutional and political failures (Evenson & Gollin, 2003) and inadequate purchasing power of the rural poor (Lee, 2005) that has led to low productivity of the agricultural sector (FAO, 2010; World bank, 2011). In this regard, Sustainable Agricultural Intensification (SAI) has recently been promoted, particularly in Sub Saharan African, to increase per capita food production. However, it is unclear why farmers report low adoption levels of SAI (Reij & Smaling, 2008) despite the many benefits that it offers.This project helps narrow this knowledge gap by exploring how farm households' package SAI practices and the determinants of such choices.

We consider adoption of packages including any of the ten SAI practices: (i) Maize legume Intercrop; (ii) Crop rotation; (iii) Use of animal manure; (iv) Minimum tillage; (v) Fertilizer; (vi) Improved seed varieties; (vii) Herbicide use; (viii) Pesticide use; (ix) Short term soil and water conservation; and (x) Long term soil and water conservation. This is the first study to use K-modes clustering to package SAI practices. We also control for unobserved individual heterogeneity by employing a random effect multinomial logit model. From the K-modes algorithm, we identified five distinct classes of SAI packages namely: (i) traditional soil restoring; (ii) yield enhancing; (iii) yield enhancing and protecting; (iv) yield enhancing and traditional soil restoring; (v) yield enhancing, yield protecting, and traditional soil restoring.

The estimates show spatial and temporal differences in uptake of different SAI cluster. Other key determinants of adoption of the various clusters include land tenure security, formal education, farm size, plot soil quality and slope, households saving and value of assets, livestock value and unit. Cropping system also determines the type of SAI cluster that farmers adopt. This implies that a one-size-fits-all SAI package is ill-suited to all farmers. Thus packaging SAI into different sets that fit solution to local needs and context can be an effective way to enhance SAI adoption and be valuable in guiding future program design.

PhD candidate Wilckyster N. Nyarindo analysed rural household survey panel data collected in 2011, 2013 and 2015 by the Adoption Pathway Project (APP) in Kenya.

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

AGRI2299 – International Fieldwork in Agribusiness – A New Colombo Plan Project

Project Team: Prof Steven Schilizzi, Jacob Hawkins

Collaborating institution: UWA; Vietnam National University of Agriculture

This is the third year that AGRI2299 has been offered, giving up to 20 UWA students the opportunity to travel to Vietnam and learn about the country's agricultural and agribusiness systems. The 2018 project involved traveling with 18 UWA students to Vietnam National University of Agriculture for an intensive two week course with 25 VNUA students on Vietnamese agricultural cooperatives. The students were grouped into teams of two UWA students with two to three VNUA students. All the students attended lectures by VNUA and UWA staff (mostly in English, but some in Vietnamese) with student team members translating and clarifying for each other in lectures. The students travelled to nearby farms on two full-day field trips and talked with agricultural cooperative managers and workers, focusing on how Vietnamese cooperatives access markets. In their teams, the UWA and VNUA students studied, analysed, and presented on aspects of production, food supply chains, marketing, government policies, food safety, and cooperative management. Accommodation and most activities were on the VNUA campus. The UWA and VNUA students developed their teamwork playing soccer together and built strong connections and friendships exploring Ha Long Bay and Hanoi, discovering local history, culture, language, and food.

This project was funded by the New Colombo Plan

9: Students involved in AGRI2299.

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 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 twelfth consecutive event, with eight students from the Faculty of Science and Faculty of Arts, Business, Law and Education presenting.

UWA's Senior Deputy Vice-Chancellor Professor Simon Biggs gave the opening address, and the two sessions were chaired by Dr Nicolas Taylor, ARC Fellow, Centre of Excellence in Plant Energy Biology, and Associate Professor Megan Ryan, UWA School of Agriculture and Environment.

The presentations can be viewed at **ioa.uwa.edu.au/publications/showcase.**

Ms Candy Taylor	Genetic dissection of flowering time to create adapted and high yielding narrow-leafed lupin crops
Mr David Minemba	Understanding the rhizosphere properties of sweet potato
Ms Amriana Hifeza	Can we reduce green house gas emissions in ruminants by using agricultural waste
Mr Michael Wallace	Developing ciprofloxacin analogues against plant DNA gyrase: a novel herbicide mode of action
Mr Ali Oumer	Drivers and Synergies in the Adoption of Sustainable Agricultural Intensification Practices: A Dynamic Perspective
Ms Jolene Otway	Bringing soil carbon modelling to the farm gate
Mr Trung Tuan Pham	Factors influencing the member value in agricultural co-operatives in Vietnam
Mr Yaseen Khalil	Fate of pre-emergence herbicides intercepted by residues in conservation agriculture systems

1: UWA PhD students shine at the 2018 Postgraduate Showcase.


1

IOA Industry Forum

Disruptive technologies: a new revolution in agriculture

The 12th UWA Institute of Agriculture Industry Forum was held in July and saw 200 diverse attendees spanning industry, academia and students, eager to learn more about the role technology will play in the future of agriculture.

This year's topic, Disruptive technologies: a new revolution in agriculture, covered remote sensing, robotics, artificial intelligence and BigData and the impact these technologies will have on the food production value chain.

Chair of IOA's Industry Advisory Board Dr Terry Enright opened the event, welcoming Minister for Water; Fisheries; Forestry; Innovation and ICT; Science, the Hon Dave Kelly. In his address, Minister Kelly congratulated UWA for again ranking first in Australia for agriculture science and 14th in the world.

The keynote address was delivered by CSIRO's Digiscape Future Science platform leader Dr Andrew Moore, who highlighted the effect new technologies will have on food production and the benefits of combining multiple technologies. Dr Moore also discussed how the fourth industrial revolution technologies will transform not just the terms of production but the social connection too.

Director of AgWorld, Mr Matthew MacFarlane, spoke about a number of Perth based AgTech start-ups. AgTech has evolved to include drones, satellites, seed tech, Internet of Things (IoT) devices and BigData. While privacy remains a concern, the outlook is positive. Start-ups are now focusing on finding customers before building new technology as the model shifts away from building without a client in mind.

Presenting on global views of automation in farm technology, were Mr Ben White and Mr Josh Giumelli from the Kondinin Group. They discussed where the technology is headed as improvements in GPS can bring pinpointing a location accurately to within 10cm.

Tammin farmer Mr Brad Jones presented as a case study of his grain farm with DPIRD economist Dr Brad Plunkett. Mr Jones is using continuous improvement to disrupt down the cost curve on his farm. Through better crop and soil data collection he can run his farm more efficiently.

The final presenter Dr Andrew Guzzomi from UWA's Faculty of Engineering and Mathematical Sciences and IOA discussed engineering innovations for food production at UWA. He gave an overview of agricultural engineering research and development activities at UWA including how infrared technology can be applied to soil crops to kill weeds when still small.

The forum closed with a panel discussion, led by Dr Manjusha Thorpe from GRDC during which the speakers fielded questions from the audience.

The Industry Forum was supported by CSBP Fertilisers through the CSBP and Farmers Ltd Golden Jubilee of Agriculture Science Fellowship. For the full program and access to presentations, see ioa.uwa.edu.au/publications/industry-forum

2: The 12th consecutive annual Industry Forum looked at how disruptive technologies are shaping the future of agriculture.

Dowerin Field Days

The IOA team joined the DPIRD exhibition at the Dowerin Field Days again this year, held on 29-30 August 2018. The theme of the 2018 Dowerin Field Days was *Women in Agriculture*, to strengthen the positive profile of women and celebrate their contribution to agriculture and business.

PhD students Bonny Stutsel and Daniel Kidd shared their research with field day attendees and the Hon Alannah MacTiernan, Minister for Regional Development, Agriculture and Food. The IOA display included the drone which Bonny uses in her research to measure frost risk in crops, and serradella plants which Daniel uses in his research as a model species for reducing P fertiliser inputs in dryland pastures.

Several Masters students and staff from the School of Agriculture and Environment attended the event as well. Under the guidance of Dr Ken Flower, the students learnt about the latest advances in machinery and precision agriculture.

The Massive Open Online Course (MOOC) “Discover Best Practice Farming for a Sustainable 2050”, which launched October 2017, was also widely advertised to field day attendees. Read more about this on page 78.

3: Prof Kadambot Siddique and PhD students Daniel Kidd and Bonny Stutsel discuss new technologies in agriculture with Hon Alannah MacTiernan at Dowerin Field Days.

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 26-27 February 2018.

Five UWA students studying agriculture including PhD candidates Candy Taylor, Daniel Kidd, and Jinyi Chen, Master of Agricultural Science student Guido Ramirez Caceres and undergraduate student Laura Bryant were supported by the Careers in Grain capacity building project to attend the event.

During the meeting, GRDC chairman John Woods said the GRDC is investing in three soils and crop nutrition research projects in WA in response to grassroots feedback. The biggest of the three soils and nutrition projects is worth a total of $9.7 million across five years and aims to improve WA grower profitability through more efficient nutrient use. This investment will be led by UWA, through the SoilsWest alliance with DPIRD, along with Murdoch University and UA, with involvement from other grains industry stakeholders. The project will improve knowledge about nitrogen cycling and availability, soil phosphorus and potassium storage, sources of nutrient supply and responsiveness of crops.

A copy of all presentations can be downloaded at www.giwa.org.au/2018researchupdates.

4: PhD candidates Daniel Kidd and Candy Taylor at the UWA stand at GRDC Research Updates.

Visitors to IOA

Over 20 visitors from nine countries were welcomed to IOA in 2018. 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 2018, see ioa.uwa.edu.au/publications/newsletters

5: Dr Nik Callow shows Rossmoyne Senior High School students how to use a drone.

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, September 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 2018, IOA solidified its social media presence on Twitter @IOA_UWA, and the number of followers grew to 800.

Public Lectures and Special Seminars

In 2018, IOA hosted ten public lectures:

Date	Presenter	Organisation	Title
15 March	Dr David Johnston	Animal Genetics and Breeding Unit, University of New England, Armidale	**Alan Servier Memorial Lecture** Beefing up the West with genetics
24 May	Professor Om Parkash Dhankher	Plant and Soil Science Graduate Program, Stockbridge School of Agriculture, University of Massachusetts	Developing climate resilient crops via manipulating novel stress-associated proteins
7 June	Professor Frans Swanepoel	Centre for Advancement of Scholarship, University of Pretoria, South Africa	Towards Zero Hunger (SDG2) in Africa
5 July	Professor Manny Delhaize	CSIRO Agriculture and Food, Black Mountain laboratories, Canberra	From aluminium tolerance to Twisted Sisters: Root research at the CSIRO Black Mountain Laboratories
10 August	Professor Kate Wright	Dean, Graduate Research School	CSIRO Industry PhD Program: Work-ready, industry-focussed researchers to bridge the research-industry divide in Australia
7 September	Professor Surinder Banga	Centre of Excellence on Brassicas, Department of Biotechnology, Government of India	A plant breeder's perspective of polyploidy: examples from canola and mustards
2 October	Professor Rajeev Varshney	Global Research Program Director, Genetic Gains, ICRISAT	Translational genomics for accelerating genetic gains in grain legumes
6 November	Professor Eric Danquah	Department of Crop Science, College of Basic and Applied Sciences, University of Ghana	Strategic Partnerships for Agricultural Innovation and Entrepreneurship in sub-Saharan Africa
27 November	Dr Raj Paroda	Former Director General, Indian Council of Agricultural Research and Secretary, Department of Agricultural Research and Education, Government of India	**Hector & Andrew Stewart Memorial Lecture 2018** Innovation led agricultural growth and sustainable development goals (SDGs)

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 2018. A substantial amount of media coverage was generated in local, rural, national and international print, broadcast and online media.

Date	Title
16 February 2018	Lupins and anti-inflammatory properties
5 March 2018	Farmers markets fuel local economy
8 March 2018	Promising biocontrol for Sclerotinia Rot
17 April 2018	Calm ewes reproduce more than nervous ewes
19 April 2018	Modern science show Roman wheat farming advice was highly accurate
26 April 2018	The business of honey
18 May 2018	Advances in drought-tolerant wheat research
25 May 2018	Research into antibacterial properties of honey showcased at conference
29 May 2018	Neglected and Underutilised species to achieve zero hunger (SDG2)
21 June 2018	Critical elements to maintain member loyalty in co-operatives
5 July 2018	UWA partners AgTech hub to accelerate innovation
17 July 2018	Chickpea can mine phosphorus bound in soils
23 July 2018	Virtual reality makes learning about plant science fun
23 August 2018	The UWA Institute of Agriculture releases Annual Research Report 2017
29 August 2018	UWA launches new centre for Australia-Africa research
1 October 2018	Native shrubs the new superfeed for livestock
9 October 2018	All welcome to stargaze on UWA farm
19 October 2018	Understanding enzyme could help produce frost-resistant crops
26 October 2018	UWA plant breeder elected Fellow of the Australian Academy of Technology and Engineering
30 October 2018	Dwarf cattle breeds make cool cows
12 November 2018	WA research to help farmers make more informed decisions
20 November 2018	Farmers' perspective vital to long-term improvements in agricultural practices
12 December 2018	First Australian elected to African Academy of Sciences

Outreach and teaching activities at UWA Future Farm

In 2018, UWA Future Farm 2050 (FF2050) hosted approximately 620 visitors, comprising of students from UWA and other Australian universities, international students and visiting academics (including Inner Mongolian Agricultural University China, Shanxi Academy of Agricultural Science China, Institute for Rural and Regional Research Norway, Newcastle University Business School UK, The German Farmers' Association Berlin, SupAgro Montpellier France, UWCSEA International School Singapore, University of Pretoria), Freie Universtat Berlin, Chinese Australia Executive Leadership Program and Indian government representatives. Ridgefield was again visited by regional and urban community members with an interest in FF2050 project and UWA Agriculture, including two Perth-based Rotary Clubs.

The Massive Open Online Course (MOOC) "Discover Best-Practice Farming for a Sustainable 2050" which launched October 2017, saw an impressive 3160 participants enrol in 2018, resulting in 4000 enrolments since inception. FF2050 tours were additionally provided for interested participants who successfully completed the MOOC, which has already included international visitors from Ireland. This free course provides an overview of the four key enterprises of the FF2050 Project, sustainable agriculture in general and UWA. Professor Phil Vercoe presented this MOOC at Colorado State University, April 2018.

Key activities:

- FF2050 Project Committee Members Mr Patrick Beale and Dr Susan Bailey attended the official opening of the Pingelly Recreation and Cultural Centre 31 August 2018.
- The new Student Learning Hub was opened in 2018, following receipt of the 2017 People's Choice Award for Alumni Funds. As well as desk-top computers, an additional five tablet computers were purchased providing greater flexibility and capacity for research in the field.
- Throughout 2018 Dr Susan Bailey maintained engagement with local Pingelly Community and Pingelly Noongar elders to develop for engagement and potential research projects with the FF2050 Project Committee Members, funded by a Community Funds Grant.
- In conjunction with the International Centre for Radio Astronomy Research (ICRAR) and SciTech, FF2050 hosted Pingelly Astrofest 2018 which was attended by approximately 130 local and city visitors. ICRAR and SciTech staff provided telescopes and expert commentary on solar observations, astrophotography and viewing of the Pingelly night skies. Visitors could also explore Scitech Spacedomes and science shows.
- In 2018 Perth hosted Australia's premier lamb industry expo, LambEx. LambEx promotes Australian lamb and wool producers as world leaders with significant international trading relationships and leverage to place LambEx 2018 on the world stage. Approximately 40 delegates toured FF2050 as part of the LambEx Field Tour options with UWA research being translated to farmers, researchers and community members. LambEx 2018 event partners were Meat & Livestock Australia, the WA Government Department of Primary Industries and Regional Development and WAMMCO.
- Professor Graeme Martin and Emeritus Professor Lynette Abbott presented on the FF2050 Project to The Shire of Brookton Regenerative Farming Forum promoting success of the regeneration projects underway at FF2050.
- Merino Lifetime Productivity (MLP) Field Day was hosted at UWA FF2050 with engagement with 75 local community and industry members on the project and Members of the Worldwide Universities Network visited FF2050 to engage with local farmers and indigenous community. Both events provided agricultural students (SNAGs) opportunities to attend, network and fundraise via a sausage sizzle.
- Professor Graeme Martin presented to 20 members of the Chinese Australia Executive Leadership Program (CAELP) on the FF2050 Project.

- Professor Kadambot Siddique provided a tour of FF2050 to Dr Raj Paroda, former Director General, Indian Council of Agricultural Research and Secretary, Department of Agriculture Research and Education, Government of India, November 2018.
- Throughout 2018 FF2050 Project continued commercial engagements with Roesner Engineering (Marshall Multispread), CSBP, AusPlow Farming Systems (Airseeder) to establish opportunities for partnerships.
- 2018 saw the beginning of a four year collaboration with Murdoch University on an Australian Wool Innovation Project at FF2050 as an add-on from the Merino Lifetime Productivity Project already underway.
- In March 2018, Dr Andrew Guzzomi, Faculty of Engineering and Mathematical Sciences and member of FF2050 Project received two awards: The 40under40 awards which recognise passion, vision, achievements and contribution to the future of WA; and UWA award for Teaching Excellence. Dr Guzzomi specialises in Agricultural Engineering within the FF2050 Project.

The FF2050 Project continues to gain momentum and reputation in schools, supported by close collaboration with Alysia Kepert, Department of Education Agriculture Curriculum Advisor. FF2050 Project promoted Astrofest school engagement with Pingelly regional schools; presentation of Primary Extension and Challenge (PEAC) courses 'Future of Food Security' in metro primary schools; and inclusion of FF2050 in the 'Wheatbelt Science Hub Trail' for secondary students.

- 25 Year 9 Geography students from Rossmoyne Senior High School attended FF2050 for a field trip integrating digital technology and data science.
- 65 Students from Environmental Systems and Societies at the UWCSEA International School in Singapore visited FF2050 to undertake soil studies.
- Professor Graeme Martin translated FF2050 Project research to students at Cunderdin, Denmark, Edmund Price, Bindoon, Harvey, Morawa and Narrogin Agricultural Colleges.
- 15 Year 10 Specialist Agricultural Students from Kelmscott Senior High School visited UWA for presentations on FF2050 by Professor Graeme Martin.
- Teaching staff from Penrhos College visited FF2050 to film sites for educational use.

Tertiary Students visiting FF2050 included:

- 5 students for Electrical and Engineering Design Projects
- 63 students for Land Capability Assessment
- 40 students for Pasture and Livestock Systems
- 6 SNAGs
- 30 students enrolled in Agricultural/Science Masters programs

Two Masters' students commenced their studies and four PhD candidates continued their studies at FF2050, one via remote data collection.

A further three students completed Work Experience and Internships at FF2050: L Smith (UWA Masters student), Florian Wolf (The German Farmers' Association), Elise Villain (SupAgro Montpellier).

Engagement with students, teachers, metro and rural community and industry members was further promoted by FF2050 Project Team Members participation throughout 2018 at events such as Techspro, Dowerin Field Days, Royal Agricultural Show and Industry Forums amongst others, and by 28 media stories published in 2018. Nine journal papers from research based at FF2050 were published in 2018. Articles covered research on soil compaction in ripped soils, modelling to improve ecological restoration, tree diversity linked to growth, survival and damage and seismology research.

6: Over 130 people came together at UWA Ridgefield Farm to celebrate astronomy and Australian science at Pingelly Astrofest.

7: UWA welcomes Lambex participants to UWA Farm Ridgefield.

8: The Merino Lifetime Productivity Project field day was one of many outreach and engagement activities held at UWA Farm Ridgefield in 2018.

Awards and industry recognition for staff in 2018

Name	Award
Dr Andrew Guzzomi	40 Under 40 Award
Assoc/Prof Muhammad Farooq	Best University Teacher Award, Higher Education Commission of Pakistan
Ms Sabrina Davies	Westpac Future Leaders scholarship
Mr James Bidstrup	AAAC scholarship
Mr Brenton Leske	Calenup Scholarship
Ms Fangning Zhang	Mike Carroll Travelling Fellowship
Ms Yueqi Zhang	Mike Carroll Travelling Fellowship
Ms Mary-Anne Lowe	GRDC Scholarship
Professor Hans Lambers	International Society of Root Research (ISSR) Lifetime Achievement Award
Assoc/Prof Atekelty Hailu	2018 Enduring Quality Award, Canadian Agricultural Economics Society
Adj/Prof Ashwani Pareek	2018 Visitor's Award for Technology
Dr Michael Considine	ARC Future Fellowship
Hackett Professor Kadambot Siddique	Kerala Cultural Association of WA, Award of Honour in recognition of outstanding achievement in agricultural science
Dr Zakaria Solaiman	Soil Science Society of China award for best paper published in the journal 'Pedosphere'.
Professor Wallace Cowling	Fellow of the Australian Academy of Engineering and Technological Sciences
Mr Md Sultan Mia	Convocation Postgraduate Research Travel Award
Hackett Professor Kadambot Siddique	Elected Fellow of the African Academy of Sciences

Research Projects

New Research Projects Awarded in 2018

Title	Funding Period	Funding Body	Supervisors
Understanding environmental drivers of flora and honey bee product production: development of Remote Sensing approaches for predicting flowering events	2017-2020	CRC for Honey Bee Products	Dr Bryan Boruff, Mr John Callow, Dr Clare Mouat, Dr Natasha Pauli, Dr Eloise Biggs, Assoc/Prof Samantha Setterfield
Development of methane sensors	2018	CSIRO	Dr Buddhika Silva, Assoc/Prof Gino Putrino, Prof Lorenzo Faraone
Structure-based investigations into new modes of action for herbicides	2018-20	ARC Discovery Early Career Researcher Awards	Dr Joel Haywood
Developing sustainable cropping systems for cotton, grains and fodder	2017-2019	North Australia Crop Research Alliance Ex CRC Project	Dr Janine Croser; Prof William Erskine
Joint Venture Agreement: Annual Legume Breeding Australia	2018-26	PGG Wrightson Seeds Australia	Prof William Erskine; Assoc/Prof Megan Ryan; Dr Phillip Nichols
Using improved markets to reduce over-extraction of groundwater	2018-20	ARC Discovery Early Career Researcher Awards	Mr MD Sayed Iftekhar
Defining factors in the control of protein turnover in plants	2018-20	ARC Discovery Projects	Prof Harvey Millar
Innovative seed technologies for restoration in a biodiversity hotspot	2018-2022	ARC Linkage Projects	Prof Richard Hobbs, Dr Todd Erickson, Dr Jason Stevens, Associate Professor Matthew Madsen, Dr Michael Forster, Mr Vernon, Mr Anthony Pekin, Mr Alan Savage
Climate-smart landscapes for promoting sustainability of Pacific Island agricultural systems - Phase 2	2018-21	Australian Centre for International Agricultural Research ACIAR	Dr Eloise Biggs, Mr Jan Helsen, Dr Eleanor Bruce, Dr Bryan Boruff, Dr Nathan Wales, Dr Viliami Manu, Prof John Connell, Ms Pyone Thu
Structure-based investigations into new modes of action for herbicides	2018-20	ARC Discovery Early Career Researcher Awards	Dr Joel Haywood
Increasing profit from N, P and K fertiliser inputs into the evolving cropping sequences in the Western Region	2017-21	GRDC	Mr Craig Scanlan, Prof Daniel Murphy, Dr Frances Hoyle, Dr Louise Barton, Prof Zdenko Rengel
Understanding the effect of air flow on fertiliser distribution	2018	Department of Industry Innovation and Science – AusIndustry: Innovation Connections	Dr Andrew Guzzomi, Dr Carlo Peressini
Elucidating trifluralin resistance in Australian major weed Lolium rigidum	2018-2020	ARC Linkage Projects	Prof Stephen Powles, Dr Qin Yu, Mr Chad Sayer
Understanding farm-household management decision-making for increased productivity in the eastern gangetic plains	2018-2020	ACIAR	Assoc/Prof Fay Rola-Rubzen
Program number 2, sub-program number 2.1 - real-time assessment of Western Australian honeys	2017-2021	CRC for Honey Bee Products	Prof Cornelia Locher, Dr Katherine Hammer

Title	Funding Period	Funding Body	Supervisors
Project 12: development of honey bee products from a biodiversity hotspot	2017-2021	CRC for Honey Bee Products	Dr Katherine Hammer, Prof Cornelia Locher
Project 5: modelling for year round high-value honey production sites	2017-2021	CRC for Honey Bee Products	Dr Michael Renton
Project 25 - pollination harmony	2017-2018	CRC for Honey Bee Products	Dr Bryan Boruff, Mr Edward Hehre
Project 4 (phd4) a “bee credit” to value bee flora in native bush hive sites	2018-2020	CRC for Honey Bee Products	Assoc/Prof Benedict White
A ‘focus farms’ study to optimize weed resistance management practices in Western Australia	2019-2020	GRDC	Dr Roberto Busi, Prof Stephen Powles, Prof Hugh Beckie, Mrs Lisa Mayer, Ms Mechelle Owen, Mr Peter Newman,
Mr Ben Whisson, Mr Garren Knell, Mr Geoff Fosbery			
Low weed seed bank persistence under sustained integrated weed management	2017-2018	GRDC	Prof Hugh Beckie, Dr Michael Ashworth
(IAEA) application of stable isotope techniques to close critical knowledge gaps with respect to pollution in agricultural ecosystems	2018-2020	International Atomic Energy Agency	A/Professor Grzegorz Skrzypek
Maximising the reproductive potential of the eat sheep industry by eliminating high oestrogen clovers, more live lambs on the ground	2018-2020	MLA Donor Company	Assoc/Prof Megan Ryan, Prof Philip Vercoe, Dr Dominique Blache, Prof Graeme Martin, Dr Zorica Durmic, Dr Kevin Foster
MDC easy as project	2018	West Midlands Group ex MLA DonorCompany	Prof Philip Vercoe
Managing subterranean clover red leaf syndrome in Western Australia stage 1	2018	Western Australian Agriculture Authority ex Meat & Livestock Australia ex Australian Wool Innovation	Assoc/Prof Megan Ryan, Dr Kevin Foster, Dr Paul Sanford
Oestrogen clovers, more live lambs on the ground	2018		Prof Graeme Martin, Dr Zoey Durmic, Dr Kevin Foster
Faba Bean in Ethiopia – Mitigating disease constraints to improve productivity and sustainability	2018-2023	ACIAR	Professor Martin Barbetti, Dr Joop van Leur, Dr Seid Kemal, Dr Ming Pei You, Adj Professor Roger Jones
CRC for developing Northern Australia - new pastures to increase livestock productivity across the north	2018-2020	Agrimix Pty Ltd ex CRC Project	Professor Zed Rengel, Mr Nick Kempe
Changing perceptions of how oxygen directs plant development	2018-2021	ARC Future Fellowships	Dr Michael Considine

Title	Funding Period	Funding Body	Supervisors
Breeding cooking time in bean (workshop)	2018	ACIAR	Professor Wallace Cowling, Hackett Professor Kadambot Siddique
Dung beetle ecosystem engineers - enduring benefits for livestock and producers via science and a new community partnership model	2017-2021	Defence Science and Technology Group (DSTG)	Associate Professor Theo Evans, Professor Leigh Simmons, Professor Raphael Didham, Dr Winn Kennington
Richgro: utilisation of a liquid b-product from a biogas facility for enriching biochar in potting mix, compost, and implications for application directly to soil	2018	Department of Industry Innovation and Science - Ausindustry: Innovation Connections	A/Professor Megan Ryan, Dr Sasha Jenkins
Developmental shifts in phosphorus-use efficiency	2018	Ecological Society of Australia Holsworth Wildlife Research Endowment	E/Professor Hans Lambers, Dr Ranathunge Ranathunge, A/Professor Erik Veneklaas, Ms Roberta Dayrell De Lima Campos
Agriculture research data cloud	2018	Federation University Australia ex Australian Research Data Commons (ARDC) (ANDS-NECTAR)	Dr Nicolas Taylor, Dr Ben Biddulph, Professor Andrew Millar, Mr John Callow, Professor Timothy Colmer, Mr Brenton Leske
Insect protein for aquaculture feed	2017-2019	Fisheries Research & Development Corporation	Dr Jan Hemmi, Associate Professor Julian Partridge, Dr Craig Lawrence, Dr Andrew Guzzomi, Ms Sasha Voss, Dr David Cook, Mr Ken Dods
Sustainable and resilient farming systems intensification in the Eastern Gangetic Plains	2018	International Maize and Wheat Improvement Center CIMMYT ex ACIAR	Associate Professor Fay Rola-Rubzen
Profitable and environmentally sustainable sub clover and medic seed harvesting	2018-2021	Rural Industries Research & Development Corporation	Professor William Erskine, Dr Phillip Nichols, Dr Kevin Foster, Dr Andrew Guzzomi, Asoociate Professor Megan Ryan
Protein structure based investigations into novel herbicides with new modes of action and plant growth pathways	2018	UWA Fellowship Support Scheme	Dr Joel Haywood
Michael Considine ARC Future Fellow - Developmental functions of oxygen and redox cues in plants	2019	UWA Fellowship Support Scheme	Dr Michael Considine
WA agriculture authority WAAA - overcoming constraints to profitable cropping on forest gravel soils in the western region	2018	WA Department of Primary Industries and Regional Development	Dr Matthias Leopold
Transcriptome sequencing to discover herbicide resistance genes in wheat (Triticum aestivum L.)	2018	Yitpi Foundation Pty Ltd	Prof Guijun Yan, Mrs Roopali Bhoite, Dr Ping Si, Hackett Prof Kadambot Siddique

New PhD research students

Fourteen students commenced their postgraduate studies in agriculture and related areas at UWA in 2018.

Name	Topic	School	Supervisor(s)	Funding Body
Khin Lay Kyu	Combined salinity and waterlogging tolerance in mungbean	UWA School of Agriculture and Environment and IOA	Prof William Erskine; Hackett Prof Kadambot Siddique; Prof Tim Colmer	John Allwright Award; ACIAR
Muhammad Azam Khan	Understanding and mapping of genes responsible for resistance against the fungal pathogen Sclerotinia sclerotiorum in canola (Brassica napus)	UWA School of Agriculture and Environment and IOA	Prof Martin Barbetti, Prof Wallace Cowling, Dr Ming Pei You, Prof Jacqui Batley	UWA-UAF Scholarship
Pratima Gurung	Screening for drought tolerance in wheat at different stages of development	UWA School of Agriculture and Environment	Prof Guijun Yan; Adj Prof Neil Turner	Self-funded
Nur Shuhadah Mohd Saad (Shu)	Characterisation of disease resistance gene in Brassicas	UWA School of Biological Sciences	Prof Jacqueline Batley	RTP scholarship
Sajeevee Kadawatha Dina Mithrage	Unravelling the role of contrasting biochars in phytoremediation activity of Industrial hemp and Buffel grass at the heavy metal contaminated soils	UWA School of Agriculture and Environment and IOA	Dr Zakaria Solaiman, Prof Zed Rengel, Prof Andy Whiteley	RTP, UPA and UWA Safety Net Top-Up
Jon Marx Sarmiento	Prospects for Inclusive Modern Agribusiness Value Chains: Improving the Participation of Smallholder Farmers in Mindanao, Philippines	UWA School of Agriculture and Environment and IOA	Dr James Fogarty, Assoc/Prof Fay Rola-Rubzen, Dr L Digal	Australia Award John Alwright Fellowship
Bibek Sapkota	Farmers' perceptions of risk, management strategies and willingness to pay for crop insurance in Nepal.	UWA School of Agriculture and Environment and IOA	Assoc/Prof Fay Rola-Rubzen, Prof Michael Burton, Dr Roy Murray-Prior	Australia Award John Alwright Fellowship
Hira Shaukat	Use of geophysical techniques to assess soil water and soil physical properties	UWA School of Agriculture and Environment and IOA	Dr Ken Flower, Dr Matthias Leopold	RTP, UPA and UWA Safety Net Top-Up
Dinesh Thapa Magar	Adoption, Impacts and Gaps in Agricultural Mechanization in Smallholder Farming Systems in Nepal	UWA School of Agriculture and Environment and IOA	Assoc/Prof Fay Rola-Rubzen, Dr Ram Pandit	SIRF and UPA
Sangay Tshewang	Above- and below ground responses of temperate perennial grass pastures to agricultural management practices	UWA School of Agriculture and Environment and IOA	Dr Zakaria Solaiman, Prof Zed Rengel, Prof Andy Whiteley, Hackett Prof Kadambot Siddique	Sir Eric Smart Scholarship for Agricultural Research
Manjula Premaratne	Nitrogen cycling in agricultural systems	UWA School of Agriculture and Environment and IOA	Professor Daniel Murphy; Dr Frances Hoyle	GRDC
Rudra Bhattarai	Wheat heat and drought tolerance	UWA School of Agriculture and Environment and IOA	Hackett Professor Kadambot Siddique; Professor Guijun Yan; Dr Hui Liu	RTP
Tanushree Halder	QTL mapping of wheat Root traits	UWA School of Agriculture and Environment and IOA	Professor Guijun Yan; Hackett Professor Kadambot Siddique; Dr Hui Liu	RTP
Mohammad Moinul Islam	Optimising industrial hemp as a new crop in Western Australian agriculture	UWA School of Agriculture and Environment and IOA	Dr Zakaria Solaiman; Hackett Professor Kadambot Siddique; Emeritus Professor Lynette Abbott; Professor Zed Rengel	RTP UWA Top Up

Memoranda of Understanding

Title	Date Signed
MOU between UWA and Udayana University, Indonesia	October 2018
Letter of extension of the MOU between UWA and Lanzhou University, China	24 September 2018
MOU between UWA and Acharya N.G. Ranga Agricultural University, India	17 September 2018
MOU between UWA and Oterra	4 June 2018
MOU between UWA and the Higher Education Commission, Pakistan for a joint scholarship program	17 May 2018
MOU between UWA and Tuscia University, Italy	9 February 2018

The UWA Institute of Agriculture Staff

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The Theme Leaders co-ordinate research, development and related activities in their respective areas. It is chaired by IOA Associate Directors Professor Phillip Vercoe and Professor Wallace Cowling.

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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.

Dr Terry Enright (Chair)
Farmer

Mr Rod Birch
Farmer

Dr Dawson Bradford
Farmer, Chairman of Directors, WAMMCO Int

Mr Rob Dickie (to June 2018)
Government and Industry Relations,
CBH Group

Mr Tym Duncanson
Strategic Projects, Science Planning
and Directorate, DPIRD

Mr Philip Gardiner
Farmer

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

Prof Tony O'Donnell (to May 2018)
Pro Vice-Chancellor and Executive Dean,
Faculty of Science, UWA

Dr Michael Robertson
Deputy Director, CSIRO

Mr Shane Sander (to September 2018)
Consultant, ACCC

Prof Kadambot Siddique,
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Hackett Professor of Agriculture Chair
and Director, IOA, UWA

Mr Simon Stead (from August 2018)
Director, CBH Group

Mr Ben Sudlow
Manager, Fertiliser Sales and Marketing, CSBP

Ms Tress Walmsley
CEO, InterGrain

Mr Neil Young
Farmer

Ms Bianca Tabbakh (Executive Officer)
Business Manager, IOA, UWA

2018 Master Publication List

Peer Reviewed Journals

Abbas G, Chen Y, Khan FY, Feng Y, Palta JA and Siddique KHM (2018). Salinity and low phosphorus differentially affect shoot and root traits in two wheat cultivars with contrasting tolerance to salt. *Agronomy* **8**: 155

Abbott LK, Macdonald LM, Wong MTF, Webb MJ, Jenkins SN and Farrell M (2018). Potential roles of biological amendments for profitable grain production – A review. *Agriculture, Ecosystems and Environment* **256**: 34-50.

Abdullah AS, Turo C, Moffat CS, Lopez-Ruiz FJ, Gibberd MR, Hamblin J and Zerihun A (2018). Real-Time PCR for diagnosing and quantifying co-infection by two globally distributed fungal pathogens of wheat. *Frontiers in Plant Science* **9:**1086

Adams IP, Fox A, Boonham N, Jones RAC (2018). Complete genomic sequence of the potyvirus Mashua virus Y, obtained from a 33-year-old mashua (Tropaeaolum tuberosum) sample. *Microbiology Resource Announcements* **7**:e01064-18.

Adams IP, Abad J, Fribourg CE, Boonham N, Jones RAC (2018). Complete genome sequence of *Potato virus T* from Bolivia obtained from a 33-year-old sample. *Microbiology Resource Announcements* **7**:e01066-18.

Adams IP, Boonham N, Jones RAC (2018). A 33-year-old plant sample contributes the first complete genomic sequence of *Potato virus U. Microbiology Resource Announcements* **7:**e01392-18.

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Ahmadi J, Pour-Aboughadareh A, Fabriki-Ourang S, Mehrabi AA and Siddique KHM (2018). Screening wheat germplasm for seedling root architectural traits under contrasting water regimes: potential sources of variability for drought adaptation. *Archives of Agronomy and Soil Science* **64**(10)**:** 1351-1365.

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Al-Saady NA, Nadaf SK, Al-Lawati AH, Al-Hinai SA, Al-Subhi AS, Al-Farsi SM, Al-Habsi KM and Siddique KHM (2018). Germplasm collection of Alfalfa (*Medicago Sativa L.*) in Oman. *International Journal of Agriculture Innovations and Research* **6** (5): 218-224.

Al-Saedi R, Smettem K and Siddique KHM (2018). Nitrogen removal efficiencies and pathways from unsaturated and saturated zones in a laboratory-scale vertical flow constructed wetland. *Journal of Environmental Management* **228:** 466-474.

Alamery S, Tirnaz S, Bayer P, Tollenaere R, Chaloub B, Edwards D and Batley J (2018). Genome wide identification and comparative analysis of NBS-LRR resistance genes in *Brassica napus. Crop and Pasture Science* **69:** 79-93.

Amir AA, Kelly JM, Kleemann DO, Durmic Z, Blache D and Martin GB (2018). Phyto-oestrogens affect in vitro fertilization and embryo development in sheep. *Reproduction, Fertility and Development* **30**: 1109-1115. DOI: 10.1071/RD16481

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Busi R, Porri A, Gaines TA and Powles SB (2018). Pyroxasulfone resistance in *Lolium rigidum* is metabolism based. *Pesticide Biochemistry and Physiology* **148:** 74-80.

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Camkin J (2018). International case studies in successful basin management. *Capacity Development Programme on Basin Management*. Hohai University, Nanjing, China. 23 October 2018.

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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
AHRI Australian Herbicide Resistance Initiative
AI Artificial Intelligence
AI-Com Agricultural innovations for communities
AIM Australian Institute of Management
ANABP Australian National Apple Breeding Program
APP Adoption Pathway Project
APRH Portuguese Water Resources Association
APSIM Agricultural Production Systems Simulator
ARC Australian Research Council
ARF Agrarian Research Foundation
aSSD Accelerated Single Seed Descent
AWI Australian Wool Innovation
BARI Bangladesh Agriculture Research Institute
BAU Bangladesh Agricultural University
BCCM Business Council of Co-operatives and Mutuals
BLUP Best linear unbiased prediction
CA Conservation Agriculture
CAS Chinese Academy of Sciences
CAAS Chinese Academy of Agricultural Sciences
CAELP Chinese Australia Executive Leadership Program
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
CFD Computational Fluid Dynamics
CIBER Centre For Integrative Bee Research
CIMMYT International Wheat and Maize Improvement Center
CME Co-operative and Mutual Enterprise
CNV Copy Number Variation
COGGO The Council of Grain Growers Organisations Limited
CSIRO Commonwealth Scientific & Industrial Research Organisation
CRC Cooperative Research Centre
CRCHBP Collaborative Research Centre for Honey Bee Products
CSIRO Commonwealth Scientific and Industrial Research Organization
DDLS The Diagnostic Laboratory Services (At DPIRD)
DEGs Differentially Expressed Genes
DPIRD Department of Primary Industries and Regional Development, Western Australia
DNA Deoxyribonucleic Acid
DWER Department of Water and Environmental Regulation
ERT Electrical Resistivity Tomography
EU European Union
FAIR Findable, Accessible, Interoperable, Reusable
FAOSTAT Food and Agriculture Organization Corporate Statistical Database
FBIP The Farmer Behaviour Insights Project
FF2050 Future Farm 2050 Project, UWA Farm Ridgefield
GBS Genotyping by sequencing
GHG Greenhouse Gas
GIWA Grains Industry Association of WA
GO Gene ontology
GRDC Grains Research and Development Corporation
GPS Global Positioning System
ICA International Co-operative Alliance
ICARDA International Centre for Agricultural Research in the Dry Areas
ICRISAT International Crops Research Institute for the Semi-Arid Tropics
EMI Electromagnetic Induction
FEC Faecal Egg Count
FGDs Focus Group Discussion
FTL Forage Tree Legumes
GPR Ground Penetrating Radar
HT Heat Tolerance
HWSC Harvest Weed Seed Control
ICEWaRM International Centre of Excellence in Water Resources Management
ICRAR International Centre for Radio Astronomy Research
IndoGAP Indonesian Good Aquaculture Practice
IOA The UWA Institute of Agriculture
IoT Internet of Things
INRA French National Institute for Agricultural Research
IWA International Water Association
IWYP International Wheat Yield Partnership
IT Information Technology
KASP Kompetitive Allele Specific
LiDAR Light Detection and Ranging
LPDP Indonesia Endowment Fund for Education
MAF Ministry of Agriculture and Fisheries, East Timor
MAS Marker-assisted Selection
MLA Meat and Livestock Australia
MOOC Massive Open Online Course
NAAS National Academy of Agricultural Sciences, India
NAM Nested association marker
NARC Nepal Agricultural Research Council
NILs Near isogenic lines
NPZ Norddeutsche Pflanzenzucht
NSW New South Wales
OCS Optimal Contribution Selection
P Phosphorus
PAV Presence/Absence Variation
PBA Pulse Breeding Australia
PCA Principal Component Analysis
PCR Polymerase chain reaction
PEAC Primary Extension and Challenge
PHS Pre-harvest Sprouting
PUE P Use Efficiency
QTL Quantitative trait locus
R&D Research and Development
RDE&A Research, Development, Extension and Adoption
RGAs Resistance Gene Analogs
RGI Rapid Gene Introgression
RIL Recombinant inbred lines
RIRDC Rural Industries Research and Development Corporation
RNA Ribonucleic Acid
RTP Research Training Program scholarship
SA South Australia
SAgE School of Agriculture and Environment, UWA
SAI Sustainable Agricultural Intensification
SARDI South Australian Research and Development Institute
SbDV Soybean Dwarf Virus
SCFAs Short-chain fatty acids
SIRF Scholarship for International and Research Fees
SNPs Single Nucleotide Polymorphisms
SRFSI Sustainable and Resilient Farming Systems Intensification
UAF University of Agriculture, Faisalabad, Pakistan
UAV Unmanned aerial vehicle
UPA University Postgraduate Award
UQ University of Queensland
UNTL National University of Timor-Lorosa'e, East Timor
UWA The University of Western Australia
VIC Victoria
VFCW Vertical Flow Constructed Wetlands
WA Western Australia
WANTFA Western Australian No-Tillage Farmers Association
WUN Worldwide Universities Network
VNUA Vietnam National University of Agriculture
WAMMCO Western Australian Meat Marketing Co

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