



THE UNIVERSITY OF  
**WESTERN  
AUSTRALIA**

The UWA Institute of Agriculture

# Annual Research Report

# 2016

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 R, D, E & A in Western Australia and in relevant national and international issues.

Front Cover Image: PhD students Bonny Stutsel and Mary Murphy setting up the field experiments.





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## Director's overview

“In the 2016 QS World University Rankings by Subject ([www.qs.com](http://www.qs.com)), Agriculture and Forestry at UWA continued the upward trend and jumped three places to 38 in the world.”

This year marks the tenth anniversary of The UWA Institute of Agriculture (IOA) since the institute was re-established in 2007. IOA was first established in 1936 to provide critical research facilities and staff for the effective training of professional agriculture graduates and scientists at the postgraduate level. However, formal activities of IOA discontinued at sometime between 1983 and 1984.

IOA in its current form was officially launched in March 2007 by the late Hon Kim Chance, former WA Minister for Agriculture and Food; Forestry. The then UWA Vice Chancellor, Professor Alan Robson, stressed the importance of the University's commitment to agriculture and natural resource management teaching and research, with the intention to maintain its premier position at the regional, national and international levels through IOA activities.

In March, we released IOA's five-year Strategic Plan at an event attended by approximately 80 members of the agriculture industry and scientific community. The strategic plan provides an important framework and direction IOA takes to advancing agriculture research, innovation and technology, and importantly in capacity building to help other countries adopt the technologies being developed.

In the 2016 QS World University Rankings by Subject ([www.qs.com](http://www.qs.com)), Agriculture and Forestry at UWA continued the upward trend and jumped three places to 38 in the world. In Shanghai Jiao Tong University's Academic Ranking of World Universities ([www.shanghairanking.com](http://www.shanghairanking.com)), UWA improved its rank to 24th in the world for Life

and Agricultural Sciences. UWA also improved its rank in the National Taiwan University Ranking 2016 (<http://nturanking.lis.ntu.edu.tw>) for the field of Agriculture, to 29th in the world. This is a significant achievement made possible by committed partners, dedicated staff, challenging opportunities and strong support from the funding bodies and industry.

IOA continued to have significant engagement with all faculties at UWA with research activities being conducted across five key research themes: Crops, Roots and Rhizosphere; Sustainable Grazing Systems; Water for Food Production; Food Quality and Human Health; and Agribusiness Ecosystems. The Theme Leaders met regularly throughout the year to harness UWA's capabilities in collaborative, cross-faculty, multidisciplinary research in agriculture and related areas.

Effective communication of agricultural research and training activities at UWA to industry, farmer groups, collaborators, funding bodies and alumni is the cornerstone of IOA's mandate.

Over 200 students visited UWA Farm Ridgefield as part of their undergraduate studies or postgraduate field work during 2016. In addition, student volunteers contributed to planting 4,370 native trees and shrubs this year. The trees were planted in partnership with Greening Australia as part of the FF2050 Project and the federally-funded 20 Million Trees Project, to rehabilitate non-arable areas.

In collaboration with the International Centre for Radio Astronomy Research (ICRAR), a Pingelly Astrofest event was held in September on UWA Farm Ridgefield, bringing approximately 300 people from the surrounding community and city to the farm. Due to the success with engaging with the rural community, we intend to continue hosting the Pingelly Astrofest at the farm every two years.



## Chair's message

In 2016 the United Nations Food and Agriculture Organization (FAO) designated it as the International Year of Pulses, and proved to be one of the highlights of IOA's communications calendar. The year-long campaign to increase public awareness about the important contribution of pulses to sustainable cropping systems, and to food and nutritional security, particularly in developing countries, included several international and local presentations, and a pulse display in the Farm 2 Food Pavilion at the IGA Perth Royal Show. UWA staff, students and associates donated more than 150kg of pulses to Foodbank WA.

A total of 39 media statements were distributed throughout the year generating coverage in the regional and agricultural press. Annual engagement activities such as the public lecture series, the Postgraduate Showcase and Industry Forum were well received and well-attended by our key stakeholders and general community. IOA's social media presence on Twitter (@IOA\_UWA) was solidified with the number of followers doubling to 310 by the end of 2016.

I am pleased to present the 2016 Annual Research Report which reflects the significant progress and achievements of our members. I wish to thank IOA staff, associates, 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 not only throughout 2016, but for their support to the institute over the past ten years.

### **Professor Kadambot Siddique**

AM, CitWA, FTSE, FAIA, FNAAS, FISPP  
Hackett Professor of Agriculture Chair and Director  
The UWA Institute of Agriculture  
The University of Western Australia

Agriculture is increasingly reliant on multidisciplinary developments in engineering, health, business and the humanities. Drawing expertise from across faculties and schools, IOA has achieved much in the past year.

The IOA Industry Advisory Board remains very engaged in providing input into the work of IOA, while recognising the need to maintain a high degree of academic endeavour, and at the same time, retaining a strong link to the agricultural sector. The Board is greatly assisted in this role by the provision of extensive and high level information on IOA programs and plans.

The Board recognises that UWA Farm Ridgefield near Pingelly is a valuable asset and provides a unique research, teaching and community engagement platform. Expertise within the Board continues to provide advice in maximising the financial performance of UWA Farm Ridgefield, within its role as both a research institution and commercial farm.

Each year, the Board conducts a forum on a topical agricultural theme. Feedback consistently praises the forum for the relevance of the topic and range of aspects covered by the high calibre speakers. This year was no exception with the forum's focus on Australia's Free Trade Agreement with China, and its impact on the agriculture industry.

IOA continues to be one of UWA's key performing institutes and I would like to take this opportunity 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 to date.

### **Dr Terry Enright**

Chair of the IOA Industry Advisory Board







# 1 Crops, Roots and Rhizosphere

## Theme Leaders:

**Dr Louise Barton**, [louise.barton@uwa.edu.au](mailto:louise.barton@uwa.edu.au)

**Assoc/Prof Megan Ryan**, [megan.ryan@uwa.edu.au](mailto:megan.ryan@uwa.edu.au)

**Dr Deirdre Gleeson**, [deirdre.gleeson@uwa.edu.au](mailto:deirdre.gleeson@uwa.edu.au)

UWA has a significant strength in root science and rhizosphere biology. Active research interests include root development and architecture, and well as stress tolerance (e.g. to waterlogging, salinity, drought), and nutrient acquisition (including mycorrhizal associations and beneficial rhizo-microorganisms and nitrogen fixation) and root diseases.

The Crops, Roots and Rhizosphere theme will have three major research, development and extension components: drought, transient waterlogging and mineral nutrition; with modelling, postgraduate training and technology exchange components being a part of each of the three themes.

The focus will be on root processes and the interaction of roots and soil abiotic and biotic environments, to enhance crop performance. The importance of the root-soil interface, rhizosphere chemistry, biology and molecular ecology, will be highlighted in multidisciplinary research.

The portfolio of research aims provide a balance between field screening and trait validation on the one hand and more fundamental research on the other, where clear relevance to the grains and pasture industries is evident.





## Determination of factors responsible for aphid-borne pea seed-borne mosaic virus epidemics in peas and development of effective virus management tools

**Project team:** Adjunct Prof Roger Jones<sup>1</sup> (roger.jones@uwa.edu.au), Mr Benjamin Congdon<sup>1</sup>, Dr Michael Renton<sup>1</sup>, Dr Brenda Coutts<sup>2</sup>, Dr Joop van Leur<sup>3</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA; <sup>3</sup>New South Wales Department of Primary Industries (NSW DPI)

The field pea industry is suffering major losses from *Pea seed-borne mosaic virus* (PSbMV) epidemics. The aims of this research were to (i) collect epidemiological information including unravelling which factors influence aphid vectors, their crop arrival times and virus epidemic development, and (ii) develop a predictive model and decision support system for PSbMV control.

PSbMV incidences were determined in field pea crops and trial plots growing in southwest WA. Incidences of 2-51 per cent were found in 9/13 crops, 1-100 per cent in 20/24 cultivar plots, and 1-57 per cent in 14/21 breeding line plots. Crops and plots of 'Gunya', 'Kaspa' and 'Twilight' were frequently infected but none of resistance gene sbm1-carrying 'Wharton'.

Fourteen PSbMV isolates from various sources were sequenced and their coat protein (CP) nucleotide sequences analysed. Sequence identities and phylogenetic comparison with 39 other CP nucleotide sequences from GenBank found three PSbMV introductions have occurred to WA, one previously unknown.

When plants of gene sbm2 carrying 'Greenfeast' and 'Gunya' and sbm1 carrying 'Wharton' and 'Yarrum' were inoculated with pathotype P-2 isolate W1, resistance was overcome in some plants of each cultivar, revealing presence of resistance-breaking variants. An improved management effort by pea breeders, advisers and growers is required to diminish infection of seed stocks, avoid sbm gene resistance breakdown, and mitigate PSbMV's impact on seed yield and quality.

In pea crops, sowing seed with minimal PSbMV infection is crucial to manage its spread and consequent losses. Seed fractionation

to decrease infection in infected seed-stocks used for sowing crops was investigated. When six infected seed-lots of 'Kaspa' or 'Twilight' were passed through sieves to obtain different size fractions, PSbMV seed transmission rates to seedlings were significantly higher in <6.5 mm than >6.5 mm fractions. Passing seed through a 6.5 mm sieve can be used to: (i) provide a warning of likely high seed infection levels, and (ii) contribute towards decreasing levels below the percentage seed transmission threshold for sowing.

PSbMV stability in sap and its contact transmission between field pea plants were investigated. When infective sap was kept at room temperature and inoculated to plants in absence of abrasive, it was still highly infective after six hours and low levels of infectivity remained after 30 hours.

PSbMV was transmitted from infected to healthy plants by direct contact when leaves were rubbed against each other. It was also transmitted when intertwining healthy and infected plants were blown to simulate wind. When air was blown on plants kept at 14 to 20°C, contact transmission of PSbMV occurred consistently and extent of transmission was enhanced when plants were dusted with abrasive before blowing. In contrast, when plants were kept at 20 to 30°C, blowing rarely resulted in transmission. No passive contact transmission occurred when healthy and infected plants were intertwined. This demonstrates that PSbMV has the potential to be transmitted by contact when wind-mediated wounding occurs. This could play an important role in crops, especially in situations where contact transmission expands initial crop infection foci before aphid vector arrival.

**This research is supported by the ARC and DAFWA.**

**1 Caption:** PSbMV-induced seed coat defects in variety Kaspa. Note necrotic rings and line patterns.

## Understanding, forecasting and managing *Pea seed-borne mosaic virus* in field pea

**Project team:** Mr Benjamin Congdon<sup>1</sup> (PhD candidate; benjamin.congdon@research.uwa.edu.au), Adjunct Prof Roger Jones<sup>1</sup>, Dr Michael Renton<sup>1</sup>, Dr Brenda Coutts<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA; <sup>3</sup>New South Wales Department of Primary Industries

The goal of this PhD project was to increase understanding of *Pea seed-borne mosaic virus* (PSbMV) epidemiology and





develop a forecasting model for PSbMV epidemics in field pea crops in the WA grainbelt.

The model developed is being used to inform a decision support system (DSS) for growers and advisors to enable effective integrated disease management. The achievements of this project were a culmination of seven years of research.

2016 was an extremely successful final year for the project with a number of highlights including completing the development of the forecasting model and developing a SMS-delivered DSS to begin in the 2017 growing season.

In 2017 this work will finally extend it to growers through SMS delivery in synergy with pea blackspot forecasts. These messages will also contain recommendations on control measures and links to further information on the virus. Application and acceptance of the DSS is crucially important in improving PSbMV management as currently there is little awareness of its proliferation into most commercial seed-lots and its impact on yield and seed quality. The effectiveness of the DSS will be monitored via communication with the end-users, so that it can be improved where necessary.

**This research is supported by the ARC, DAFWA and the GRDC.**

**2 Caption:** PhD candidate Ben Congdon collecting aphid traps at a field pea data collection block in Muresk.

## A virulent new *Turnip Mosaic Virus* (TuMV) strain that breaks all TuMV resistances in *Brassica Napus*

**Project team:** Adjunct Prof Roger Jones<sup>1</sup> (roger.jones@uwa.edu.au), Ms Marine Guerret<sup>1</sup>, Dr Eviness Nyalugwe, Mr Solomon Maina<sup>1</sup>, Prof Martin Barbetti<sup>1</sup>, Dr Joop van Leur<sup>3</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA; <sup>3</sup>NSW-DPI

*Turnip mosaic virus* (TuMV) causes a serious disease of Brassica crops globally, including *Brassica napus* (canola) oilseed crops. The disease caused by TuMV was formerly held in check in Australian canola crops by presence of one or more TuMV resistance genes in all Australian cultivars, surveys of canola crops in WA and NSW revealing infection levels of only 1-5 per cent plant infection.



However, since 2012, a virulent new resistance-breaking strain of TuMV has been found causing widespread infection and reaching high infection incidences in canola crops growing in the Liverpool Plains region of NSW. This strain causes symptoms of severe leaf mosaic, leaf deformation and plant stunting in infected canola plants. In consequence, seed yield losses are high. There is widespread concern that this virulent TuMV strain will spread to *B. napus* crops in other Australian regions.

Isolates 12.2 and 12.5 of the resistance-breaking strain, and Australian TuMV isolates in pathotypes 1 (NSW-2), 7 (NSW-1) and 8 (WA Ap1) were inoculated to plants 19 canola cultivars, and isolates 12.2, 12.5 and WA-Ap1 to plants of nine other Brassicaceae species. At least one of isolates NSW-1, NSW-2 and WA Ap-1 caused one or other of four different resistance phenotypes in each of the 19 canola cultivars. Thus, all of them carried at least one of four distinct strain specific resistances. Isolates 12.2 and 12.5 always overcame all four of these resistances causing severe systemic mosaic symptoms in the 19 canola cultivars. In contrast, isolates 12.2, 12.5 and WA-Ap-1 all induced resistance phenotypes in 4/9 other Brassicaceae species (*B. oleracea*, *Camelina sativa*, *Eruca sativa*, *Raphanus sativus*) so the resistance-breaking properties were ineffective with these four species.

TuMV isolates 12.2 and 12.5 were sequenced by Illumina HighSeq 500, and their reads subjected to de novo assembly using a CLC genomics workbench to obtain complete genomes. The 12.1 and 12.5 isolate complete sequences were similar to each other but distinct from all previously sequenced Australian TuMV isolates, and fell within the overall world-B phylogroup. They therefore represent an incursion of a dangerous new, resistance-breaking TuMV strain to Australia.

Spread of this resistance-breaking strain of TuMV poses a significant threat to the canola oilseed industry. Breeding canola cultivars with resistance to this strain is a critical priority for canola breeding programs in Australia and elsewhere.

**This research is supported by DAFWA.**

**3 Caption:** Resistance phenotype (necrotic spotting) in plant of cv. Tarcoola.



## Wind spread of plant viral pathogens into northern Australia

**Project team:** Adjunct Prof Roger Jones<sup>1</sup> (roger.jones@uwa.edu.au), Mr Solomon Maina<sup>1</sup>, Dr Owain Edwards<sup>2</sup>, Dr Brenda Coutts<sup>3</sup>, Prof Martin Barbetti<sup>1</sup>, Dr Ming-Pei You<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>CSIRO; <sup>3</sup>DAFWA

To examine possible genetic connectivity between crop viruses found in Southeast Asia and northern Australia, *Papaya ringspot virus biotype W* (PRSV-W) and *Zucchini yellow mosaic virus* (ZYMV) isolates from cucurbits growing in East Timor and northern Australia were studied. East Timorese samples were sent to Australia on FTA cards. The samples were subjected to high throughput sequencing.

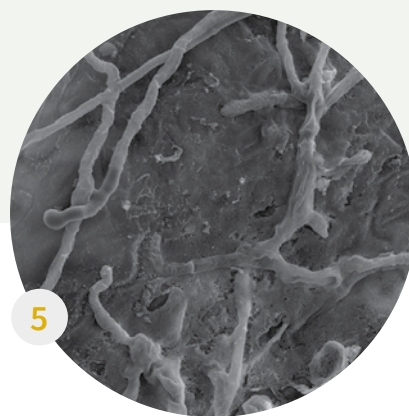
When the 17 complete PRSV genomic sequences obtained were compared with 32 others, the five from East Timor were in a different major phylogroup from the 12 Australian sequences. Moreover, the East Timorese and Australian sequences each formed their own minor phylogroups.

Recombination analysis revealed 13 recombination events amongst the 49 complete genomes. Two isolates from East Timor (TM50, TM32) and eight from Genbank were recombinants, but all 12 Australian isolates were non-recombinants. No evidence of genome connectivity between Australian and southeast Asian PRSV populations was obtained.

When the 15 complete ZYMV genomic sequences obtained were compared with 41 others, those from East Timor and Kununurra (three per location) and single sequences from Singapore and Reunion Island were in major phylogroup B. The seven Broome and two Darwin sequences were in different minor phylogroups within major phylogroup A.

Analysis of all 56 complete genomes found recombination in 12 (87 per cent) and two (5 per cent) sequences from northern Australia/Southeast Asia and the rest of the world respectively, the former's high frequency indicating selection for tropical conditions. Both parents of the recombinant Kununurra sequences were East Timorese. Phylogenetic analysis, nt sequence identities and recombination analysis provided firm evidence of connectivity between sequences from Kununurra and East Timor.

This finding has important biosecurity implications over entry of viral crop pathogens into northern Australia.



**This research is supported by the CRC for Plant Biosecurity, CSIRO and DAFWA.**

**4 Caption:** Fruit of zucchini cv. Black Jack with yellow mottling, severe malformation and diminished size caused by PRSV infection.

## Resistance against the important field pea black spot complex pathogen *Phoma koolunga*

**Project team:** Prof Martin Barbetti (leader; martin.barbetti@uwa.edu.au), Mr Hieu Sy Tran, Dr Ming Pei You, Prof Tanveer Khan

*Phoma koolunga* has recently been shown to be both widespread across Australia in association with field pea black spot and to be a highly virulent pathogen to field pea. Studies have shown that *P. koolunga* causes significant disease on leaves, stems, epicotyls, lateral and tap roots of field pea.

The aim of this research was to determine the mechanisms of resistance in field pea to *P. koolunga* and investigate the infection process of *P. koolunga* on leaf and stem of both resistant and susceptible pea genotypes.

In 2016, the highlights included finding that on both resistant and susceptible genotypes, light and scanning electron microscopy showed *P. koolunga* conidia infect stem and leaf tissues directly via appressoria or stomatal penetration, but with more infections involving formation of appressoria on stems than on leaves.

On leaves of resistant genotype, at 72 hours post inoculation, *P. koolunga* penetrated more frequently via stomata than via formation of appressoria; yet no such difference was observed on stems of resistant genotype.

In contrast, at the same time point, number of conidia infecting susceptible genotype via formation of appressoria on either or leaves was significantly greater than via stomata.

The mean germ tube length of germinating *P. koolunga* conidia on both stems and leaves of the resistant genotype was less than on susceptible genotype. In addition, there were differences in number of germ tubes emerging from conidia on resistant and susceptible genotypes.

These are the first insights into the nature of leaf and stem resistance mechanisms operating in field pea against *P. koolunga*.

**5 Caption:** Scanning electron micrograph of hyphae of *P. koolunga* entering field pea leaf via stomata. Photo: Hieu Sy Tran





## Identification of blackleg resistance across wild Brassicaceae species

**Project team:** Ms Fangning Zhang (PhD Candidate; fangning.zhang@research.uwa.edu.au), Prof Jacqueline Batley, Prof Dave Edwards, Prof Guijun Yan

This project aims to look for resistance genes to blackleg disease, caused by the fungal pathogen *Leptosphaeria maculans*, across the wild Brassicaceae species. Blackleg disease causes serious economic loss to the Brassica industry, therefore, the identification of novel resistant sources is necessary for efficient breeding. Some wild species across the Brassicaceae family show strong resistance and it is possible to transfer those resistances to canola by crossing or genetic transformation.

In this project, we plan to screen resistance of many accessions of different species with at least ten blackleg isolates collected from different geographical locations. If segregation to resistance can be found within a species, whole genome sequencing will be performed to identify the gene sequences responsible for resistance and susceptibility.

During 2016, the inoculation tests of seven isolates have been performed and a 60K SNP (single nucleotide polymorphism) array has been used to genotype DNA extracted from all the accessions. As the 60K SNP array is designed for the A and C genomes of Brassica, the calling rate of these wild species ranges mostly from 20 per cent to 60 per cent. For inoculation assays two accessions, SAR4 from *Sinapis arvensis* and COL1 from *Sinapis alba*, showed susceptibility; while all the rest of the species show strong resistance to the isolates.

Chromosome counting is being performed to confirm the species identity. Crossing between susceptible and resistant lines is currently being performed to generate a segregating population for further study and association analysis.

**This research is supported by the ARC.**

**6 Caption:** Scoring lesion size on the cotyledons following inoculation. The smaller the lesion, the more resistant the genotype.

## Expanding the Brassica germplasm base through collaboration with India and China

**Project team:** Prof Martin Barbetti<sup>1</sup> (leader; martin.barbetti@uwa.edu.au), Dr Ming Pei You<sup>1</sup>, Dr Niroshini Gunasinghe<sup>1</sup>, Prof Surinder S. Banga<sup>3</sup>, Dr Shashi K. Banga<sup>3</sup>, Dr Xi Xiang Li<sup>4</sup>, Prof Phil Salisbury<sup>2</sup>, Dr Allison Gurung<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>University of Melbourne; <sup>3</sup>Punjab Agricultural University; <sup>4</sup>Chinese Academy of Agricultural Science (CAAS)

White leaf spot, caused by the fungus *Pseudocercospora capsellae*, and *Sclerotinia* rot caused by *Sclerotinia sclerotiorum* are serious diseases across oilseed and vegetable Brassica-growing regions worldwide, including Australia. Effective host resistance is urgently needed if white leaf spot is to be economically managed.

The aim of this research was to identify new sources of resistance to *P. capsellae* and *S. sclerotiorum* across diverse oilseed, forage and vegetable crucifers, including some wild and/or weedy species, and also within and/or derived from *Brassica carinata*.

Specifically, this report relates to: (i) *P. capsellae*; field screening of 117 *B. napus*, seven lines of *B. napus* containing weedy crucifer introgression, 16 lines with *B. carinata* introgression, 56 lines of synthetic *B. napus* from *B. juncea* into *B. carinata* and *B. rapa* into *B. oleracea*, while remaining *B. napus* were commercial varieties from Australia; and, (ii), *S. sclerotiorum*, field screening of 52 Chinese genotypes of *Brassica oleracea* var. capitata, 14 Indian *Brassica juncea* genotypes carrying wild weedy *Brassicaceae* introgression(s) and four carrying B-genome introgression, 22 Australian commercial *Brassica napus* varieties, and 12 *B. napus* and *B. juncea* genotypes of known resistance.

*B. rapa* subsp. *oleifera* ATC 95966 Bo was completely resistant to white leaf spot disease. Very high resistance was observed in all five *B. oleracea* genotypes and of these *B. oleracea* var. *gongylodes* Tronchuda and *B. oleracea* var. *sabellica* extremely highly resistant. Eight *B. fruticulosa* genotypes showed high resistance.

Amongst *B. napus* genotypes, more than Australian commercial cultivars demonstrated comparatively higher resistance to white leaf spot disease than the most resistant genotypes with weedy introgression or synthetic *B. napus*, with commercial cultivars Oscar and Stubby considered to be highly resistant.



Genotypes with high-level resistance identified in this study will be of great value for developing new cultivars of oilseed, forage and vegetable crucifers with much improved levels of resistance to white leaf spot.

For Sclerotinia, 65 per cent of the *B. oleracea* var. capitata genotypes from China showed the highest levels of stem resistance, a level comparable with the highest resistance ever recorded for oilseed *B. napus* or *B. juncea* from China or Australia.

One Indian *B. juncea* line carrying weedy introgression displayed a significant level of both stem and leaf resistance. The vast majority of commercial Australian oilseed *B. napus* varieties fell within the most susceptible 40 per cent of genotypes tested for stem disease. There was no correlation between expressions of stem versus leaf resistance, suggesting their independent inheritance. A few Chinese *B. oleracea* var. capitata genotypes that expressed combined extremely high level stem ( $\leq 1$  mm length) and leaf ( $\leq 0.5$  mean number of infections/plant) resistance will be particularly significant for developing new SR resistant horticultural and oilseed *Brassica* varieties.

**This research is supported by the GRDC.**

**7 Caption:** Typical White leaf spot symptoms on foliage of susceptible canola. Photo: Martin Barbetti

## Emerging foliar diseases of canola

**Project team:** Prof Martin Barbetti (leader; martin.barbetti@uwa.edu.au), Dr Ming Pei You, Dr Margaret Uloth, Dr Niroshini Gunasinghe, Mr Akeel Mohammed, Ms Hebba Al-Lami

In Australia, in recent years increased levels of diseases such as white leaf spot (*Pseudocercospora capsellae*), powdery mildew (*Erysiphe cruciferarum*), downy mildew (*Hyaloperonospora parasitica*) and Alternaria have been observed.

Historically, all are assumed nationally to be able to cause significant losses and there is considerable evidence that they all, individually and together, currently significantly decrease grain yields of canola and are important diseases.

However, all four diseases are currently considered as 'emerging diseases' as disease incidences and severities have in general become more prominent in recent years but their incidence, severity and impacts remain to be defined.

The aim of this research was to provide new knowledge and recommendations to determine if further work is warranted in evaluating yield loss caused by white leaf spot, powdery



mildew, downy mildew and Alternaria and/or the management strategies needed to maximise the yield potential of canola in the presence of these diseases.

White leaf spot was found to be particularly prevalent, with up to 60 per cent leaves diseased, 30 per cent leaf area lost, 20 per cent leaf area collapsed and was particularly debilitating on younger canola crops, but with this effect persisting.

Downy mildew was also prevalent, particularly in WA, with up to 55 per cent of leaves diseased, 15 per cent leaf area lost and 13 per cent leaf area collapsed and was particularly debilitating on younger canola crops, but with this effect persisting.

Powdery mildew was very severe disease only on some crops approaching maturity in northern agricultural area of WA and Moree region of NSW.

Alternaria was a sporadic disease of canola crops in WA, SA, Victoria and northern NSW, with up to 10 per cent of leaves diseased and five per cent of leaf area lost to lesions.

**This research is supported by the GRDC.**

**8 Caption:** Conducting disease assessment transects across a canola field. Photo: Margaret Uloth.

## Improved subterranean clover seed production from multiple disease resistance

**Project team:** Prof Martin Barbetti<sup>1</sup> (leader; martin.barbetti@uwa.edu.au), Dr Ming Pei You<sup>1</sup>, Dr Phillip Nichols<sup>3</sup>, Prof William Erskine<sup>1</sup>, Dr Parwinder Kaur<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA

This study is using the 97-member core collection of subterranean clover, which represents around 80 per cent of the total genetic diversity within the known 10,000 accessions of the species, along with an additional 28 diverse cultivars. These 125 genotypes will be screened for their resistance against the most important diseases of subterranean clover, viz. clover scorch (*Kabatella caulivora*) - both Race 1 and 2 (seedling and adult resistance); rust (*Uromyces trifolii-repentis*); and the two most important root rot disease pathogens, *Phytophthora clandestina* and *Pythium irregulare*. This will enable the genetic control for resistance to each disease to be determined and molecular markers closely associated with resistance genes or Quantitative Trait Locus (QTLs) to be produced.



The aims of this research were to (i) determine the level of diversity within subterranean clover for resistance to the above diseases, which are key to seed production; (ii) determine the number and genome location of the genes for resistance to each target disease; (iii) identify potential parents for crossing to introduce new genes for resistance to important diseases of subterranean clover; and (iv) identify molecular markers closely linked to genes or QTLs for disease resistance.

In 2016, the results showed there to be significant variation among test genotypes against the soilborne pathogens *Pythium irregulare* and *Phytophthora clandestina* in relation to germination rate, tap root disease index, lateral root disease index, root dry weight and shoot dry weight. For example, York, L12, L75, Campeda and L13, all expressed a high level of resistance to *P. irregulare*.

Similarly, there was also variation among test genotypes against the foliar pathogens *Kabatiella caulivora* and *Erysiphe trifolii* and the most resistant genotypes have been identified.

Resistant genotypes offer breeders a basis to breed new more-resistant cultivars, particularly once quantitative trait loci have been identified for use in marker-aided selection programs as this will allow more rapid development of new highly resistant subterranean clover cultivars against these pathogens.

Together, these studies are expected in future to lead to a reduction of current high levels of damage to subterranean clover pastures caused by the major foliar and soilborne pathogens across Australia.

**This research is supported by Rural Industries Research and Development Corporation (RIRDC).**

**9 Caption:** Screening of the subterranean clover 'core' collection against soilborne pathogens. Note differences in seedling germination and plant size between genotypes as a consequence of different resistances/susceptibilities to soilborne pathogens. Photo: Ming Pei You



# Making clover pastures permanently resistant to *Phytophthora* root disease

**Project team:** Prof Martin Barbetti (leader; martin.barbetti@uwa.edu.au), Dr Ming Pei You, Dr Kevin Foster, Dr Kunmei Guo

Soilborne root disease caused by multiple races of *Phytophthora clandestina* is the single biggest limitation to productive subterranean clover pastures across southern Australia.

The aim of this research was to define the race situation for *P. clandestina* across southern Australia, identifying what pathogen races are present and in which agro-geographical regions, such that the appropriate subterranean clover cultivar resistances can be located and deployed against the prevailing races in different regions.

As part of these studies Australian subterranean clover cultivars are being screened against a combination of 30 different races of *Phytophthora clandestina* (along with other soilborne pathogens such as *Pythium irregulare*, *Aphanomyces trifolii*, and *Rhizoctonia solani* also confirmed to be present in the combined test pasture soils from across southern Australia), in order to identify effective 'field tolerance'.

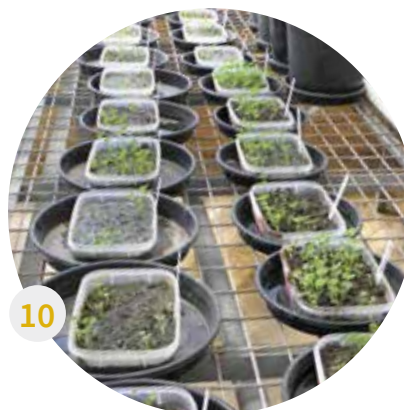
Of the tested cultivars to date, the results show the existence of clear, very strong and effective differential 'field tolerances' and 'resistances' per se to soilborne pathogens (and particularly to multi-races of *P. clandestina*).

This is not only the first time such testing of subterranean clovers for both 'field tolerances' and 'resistances' per se has been attempted to soilborne pathogens, but the first time both effective 'field tolerances' and effective 'resistances' per se have been demonstrated against the full complement of soilborne pathogens and their races.

The benefits of such have been quantified in terms of significant productivity increases in terms of less root disease, improved germination and seedling survival and, in particular, improved plant top growth in the presence of this array of races of *P. clandestina* and presence of other major soilborne pathogens.

The best of these cultivars show greatly increased productivity resulting from the greatly reduced disease impact despite the presence of massive levels of severe root disease (i.e. 'field tolerance' to disease). These experiments have also confirmed for the first time that additional 'resistance' per se against this complex of soilborne pathogens can also be identified. The latter offers significant prospects for additional greatly reduced disease levels over and above the 'field tolerance' identified, as such 'resistance' can now be combined with the 'field tolerance' so far identified in these studies.

Not only can these cultivars with general 'field tolerance' be directly deployed in situations across the agro-geographical regions to effectively manage disease in situations where multiple *P. clandestina* races occur, but their identification will also allow breeders to subsequently develop new clover



cultivars with combination of effective general 'field tolerance' against soilborne disease along with specific major gene-based race 'resistances' that will provide the first complete, durable and sustainable 'field tolerance' + 'resistance' across all 30 of the *P. clandestina* races currently prevailing across the agro-geographical regions

In addition, importantly, deployment of such 'field tolerance' + 'resistance' combinations will prevent any further proliferation of new races of *P. clandestina*.

**This research is supported by AWI.**

**10 Caption:** Screening subterranean clover cultivars for field tolerance against 30 different races of *P. clandestina*. Photo: Ming Pei You

## Managing soil-borne root disease in sub-clover pastures

**Project team:** Prof Martin Barbetti<sup>1</sup> (leader; martin.barbetti@uwa.edu.au), Dr Ming Pei You<sup>1</sup>, Dr Kunmei Guo<sup>1</sup>, Dr Alan MacKay<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>SARDI

Soilborne root diseases, caused by a range of pathogens and particularly *Phytophthora*, *Pythium*, *Aphanomyces*, and *Rhizoctonia*, are the major limitation to productive subterranean clover pastures across southern Australia.

This research aimed to identify effective and practical management techniques to reduce the pasture productivity loss during autumn-winter induced by soilborne root disease; understand the disease pathogen complexes and quantify their adverse impacts.

The development and confirmation of a successful DNA test for *Aphanomyces* has been a very significant outcome of this project that has allowed the first meaningful interpretation of DNA test results for the full range of soilborne pathogens in pastures.

Studies have highlighted the important role of 'environmental factors' in determining the severity and impact of soilborne root diseases on subterranean clover. 'Environmental factors' including soil moisture, type, temperature and nutrition profoundly determined severity and impact of soilborne root diseases; specific roles of individual factors vary depending upon the prevailing pathogen(s).





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Studies confirmed that the main pathogens causing damping-off and root diseases of subterranean clover are: *P. clandestina*, *Pythium* spp., especially *P. irregulare*, *R. solani* and *Aphanomyces trifolii*.

Studies demonstrated that root rot pathogens generally exist in the soil as complex of two to four of the abovementioned pathogens.

The main losses have now been quantified for subterranean clover pastures. For example, soilborne pathogens reduce germination by up to 70 per cent; reduce root systems up to 90 per cent; reduce shoot systems up to 85 per cent. *Pythium* reduces germination by up to 60 per cent and up to a 50 per cent loss in plant productivity; *Phytophthora* reduces germination by up to 25 per cent and a 4.5 fold loss in plant productivity; *Rhizoctonia* reduces germination by up to 90 per cent and up to 75-80 per cent loss in shoot and root production; and *Aphanomyces* reduces germination by up to 14 per cent and up to 50-55 per cent loss in shoot and root systems.

Where there are two or more pathogens, losses up to 100 per cent germination failure and total loss of root and shoot production occur.

**This research is supported by Meat and Livestock Australia (MLA).**

**11 Caption:** Sowing at one of sixteen field trials across southern Australia trialling cultivar, fertilizer, seed and foliar fungicides, grazing and cultivation treatments. Photo: John Quealy

## Strategies to provide resistance to the economically important fungal pathogen *Rhizoctonia solani*

**Project team:** Adjunct Prof Karam Singh<sup>1,2</sup> (leader; karam.singh@csiro.au), Adjunct Assoc/Prof Jonathan Anderson<sup>1,2</sup>, Dr Rhonda Foley<sup>2</sup>, Dr Kathleen DeBoer<sup>2</sup>, Mr Nicholas Pain<sup>2</sup>, Ms Hayley Casarotto<sup>2</sup>, Ms Priya Krishnamurthy<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>CSIRO

This project addresses plant disease caused by root fungal necrotrophic pathogens, a pressing problem facing Australian growers.



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The focus was on *R. solani*, which due to its large host range and lack of natural plant resistance is a major constraint for many crops, including cereals. Wheat, canola and Arabidopsis were used to identify critical components of plant resistance to.

New pathotype diversity within AG8 from WA has been identified and used comparative genomics to identify key factors that may relate to the difference in host preference.

These key pathogenicity factors may be useful for screening breeding populations for insensitive lines.

**This research is supported by the GRDC and CSIRO.**

**12 Caption:** High-throughput controlled environment screen of wheat genotypes for altered susceptibility to *R. solani*. Photo: Rhonda Foley, Jonathan Anderson, CSIRO

## Curtailing exotic fungal spore incursions into Australia

**Project team:** Prof Martin Barbeti<sup>1</sup> (leader; martin.barbeti@uwa.edu.au), Ms Papor Barua<sup>1</sup>, Dr Kirsty Bayliss<sup>2</sup>, Dr Vincent Lanoiselet<sup>3</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Murdoch University; <sup>3</sup>DAFWA

This project is testing the hypothesis that it is possible to develop and apply prototype tools to detect the contamination of carrier materials with fungal spores in relation to exotic fungal pathogens threats, and that effective methods of decontamination of contaminated carrier materials can be developed.

Preliminary CRC for National Plant Biosecurity (CRCNPB) work demonstrated that it is possible to detect fungal spores on various materials. This project now is extending the CRCNPB work to define the relative risks due to different carrier materials (e.g., clothing, skin, souvenirs, metal, wood, etc) transporting fungal spores into Australia. Additionally, it will investigate ways to mitigate these risks by investigating decontamination options.

The aims for this research were to develop new rapid methodologies and test the survivability of spores across different fungal classifications as representing exotic fungal

pathogen threats to Australia by firstly, assessing relative abilities and effectiveness of different carrier materials to act as spore carriers; and secondly, by testing effects of different carrier materials per se on spore viability.

This research also tested ability of different control measures for decontamination of infested carrier materials, including testing a wide range of methods for reliably killing of spores in situ on and/or within the carrier materials.

During 2016, a new rapid and miniaturised system using Alamar Blue (resazurin dye; 7-hydroxy-3H-phenoxazin-3-one 10-oxide) was developed for assessing fungal spore viability, using the ascomycete *Leptosphaeria maculans* (causing blackleg disease on canola) as a 'model pathogen'.

The assay is dependent on the metabolic activity of viable fungal spores to convert the dark blue of resazurin into the pink colour of resorufin. The Alamar Blue assay uses an optimised micro-titre based format that was far superior for determining fungal spore viability in comparison with current conventional techniques including trypan blue staining, a TC10 cellometer cell counter, or by assessing germination of the spores under the microscope. This new assay was also more rapid and reproducible than current conventional tests to detect viable spores. Viable spores could be reliably detected within two hours.

The effectiveness of the Alamar Blue assay was confirmed by successfully determining the relative retention times of viable *L. maculans* ascospores across a range of different potential spore-carrier materials, including steel, fabric, wood, paper, rubber and leather, over a time period of eight months.

To further confirm the wide applicability of the Alamar Blue assay, it was successfully applied to detect viable spores of fungal pathogens of diverse taxonomic groups, including *Kabatiella caulivora*, *Magnaporthe oryzae* and *Puccinia striiformis* f.sp. tritici, and also of the yeast *Saccharomyces cerevisiae*.

The successful application of the Alamar Blue assay to measure fungal spore viability in the current study has important benefits for biosecurity operations relating to faster and more reliable confirmation of viability of potential invasive exotic fungal pathogens and in minimising any consequent disease outbreaks.

**This research is supported by CRC for Plant Biosecurity.**

**13 Caption:** Schematic stepwise flow diagram of development of a miniaturized system to use materials in a cell culture plates for large samples and Alamar Blue assay for detection of viable fungal spores using *Leptosphaeria maculans* ascospores as the 'model' plant pathogen.

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### Step 1

*Leptosphaeria maculans*  
ascospores  
inoculum

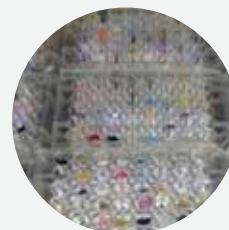


**Inoculation 10<sup>6</sup> spores/ml**



### Step 2

Plates with 0.5 cm  
pieces materials



**Add 0.1% Tween20**



### Step 3

Isolation of  
treated spores  
from tested  
materials



**Washing 40minutes {700rpm}**



### Step 4

Collection of  
residual solution  
with ascospores  
after washing



**Viability assay**



### Step 5

Viable spores will  
reduce resazurin  
to resorufin while  
producing pink  
color







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## Characterisation of Rice blast races present in Australia

**Project team:** Dr Vincent Lanoiselet<sup>1</sup> (leader; vincent.lanoiselet@agric.wa.gov.au), Dr Xiangling Fang<sup>2</sup>, Mr Dolar Pak<sup>2</sup>, Dr Ming Pei You<sup>2</sup>, Prof Martin Barbetti<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>DAFWA; <sup>2</sup>UWA

Rice blast (caused by *Magnaporthe oryzae*) is the most important disease of rice worldwide. To date the pathogen remains exotic to the Rice Pest and Disease Exclusion Zone of NSW but does occur in QLD, NT and was recently detected in northern WA.

The aim of this research is to investigate the genetic diversity and the prevalence of the rice blast races present in Australia; identify and map the distribution of rice blast races across Australia, as this is a critical prerequisite step to develop strategies for deploying existing resistant rice cultivars and for breeding new ones; and determine potential fungicidal control options for rice producers.

The rice blast isolates were characterised into five races: IA-1, IA-3, IA-63, IB-3 and IB-59. Genes Pi40, Piz-t, Pi9, Pi5(t) and Pi12(t) exhibited resistance to all the isolates belonging to five races.

In addition, two genes showed complete resistance to multiple races, viz. Pi9 that showed complete resistance to races IA-1, IA-3, IA-63 and IB-3 and Pita2 that had complete resistance to races IA-3, IB-3 and IB-59.

The EC<sub>50</sub> of a collection of fungicide-sensitive blast isolates were within the range of 0.02-2.02 and 0.06-1.91 mg L<sup>-1</sup> for azoxystrobin and propiconazole, respectively. Azoxystrobin was shown to have greater inhibitory effect on conidial germination than propiconazole.

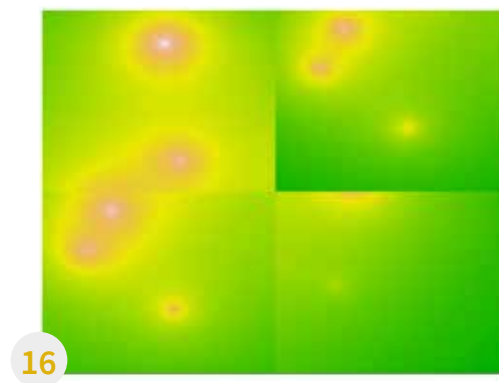
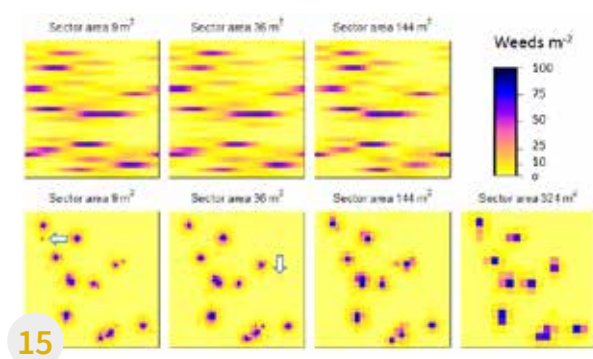
On susceptible seedlings, both fungicides completely controlled blast disease when applied the same day as inoculation. However, for pre- or post-inoculation application of fungicide, the extent of disease control was reduced, with azoxystrobin more efficacious than propiconazole. However, studies demonstrated the high degree of efficacy of these fungicides and their potential for future rice blast management in Australia

A stimulatory effect of both fungicides at low dose was observed on certain *P. oryzae* isolates and is the first report of a stimulatory effect of low azoxystrobin concentration on growth of *M. oryzae*.

For the first time, the critical role of external nutrients in promoting germ tube growth under fungicide stress conditions was highlighted.

**This research is supported by Rural Industries Research and Development Corporation (RIRDC).**

**14 Caption:** Project leader Dr Vincent Lanoiselet and Prof Martin Barbetti examining rice plants for development of blast disease symptoms.



## Stacking weed control tactics to maintain herbicide efficacy: A new spatial population model analysis

**Project team:** Ms Gayle Somerville<sup>1</sup> (PhD Candidate; gayle.somerville@research.uwa.edu.au), Dr Michael Renton<sup>1</sup>, Prof Stephen Powles<sup>1</sup>, Assoc/Prof Michael Walsh<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>University of Sydney

The aim of the four year project was to build a new stochastic, spatially defined, simulation model. The spatially orientated model of the evolution of resistance (SOMER), is designed to more accurately predict the evolution of a herbicide resistant weed population, growing within a crop field. Then, we wanted to use the model to examine alternate management practices, and their effects on the speed of herbicide resistance evolution (including multiple resistance) within a crop field.

In 2016 working with the Australian Herbicide Resistance Initiative at UWA, the effects of the natural dispersal (via pollen) and human mediated dispersal (of weed seeds) on the spread of resistance genes were examined, and the resultant rapid rise in numbers, occurring in an improperly managed population of herbicide resistant weeds.

Specifically there were two new research outcomes, achieved through the use these new simulations in SOMER. Firstly there was a calculation of the effect of harvester seed dispersal (as opposed to seed that is not collected) - which re-emphasised the need for control of weed seeds at harvest (HWSC), and second there was a better estimation of patch spread from one initially resistant plant (assuming no harvester seed dispersal) - affecting patch management recommendations, involving better estimations of how far out from a visible weed patch resistant weeds, and seeds, exist.

Some of this material was presented In September 2016, at the 20th Australasian Weeds Conference in Perth, run by the Council of Australasian Weed Societies. It was presented as part of the well-attended grain weeds advisory committee sessions, which included a successful joint concurrent panel session. Research from 2015 was presented, and this led to

number of important connections to other weed researchers, and international representatives from Bayer, which has helped support to future collaborative exchanges.

**This research was supported by the Australian Herbicide Resistance Initiative at UWA.**

**15 Caption:** Illustration of how spatial patterns in weed density are influenced by seed dispersal by a grain harvester (top row), or without seed dispersal by a harvester (bottom row) across four alternate sector sizes. These seven figures show a 10.5 hectare area. All simulations had identical seed distribution at the beginning of the second year (section 2.3), and show weed numbers/m<sup>2</sup> seven years after herbicide use began. The figures were chosen as representative of the seven scenarios (each one was selected from ten replicates).

## National pathogen management modelling and delivery of decision support

**Project team:** Dr Michael Renton<sup>1</sup> (leader; michael.renton@uwa.edu.au), Dr Remi Crete<sup>1</sup>, Dr Katarina Streit<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA; <sup>3</sup>Centre for Crop and Disease Management, Curtin

The overall aim of this project is to further the development of simulation methodology in the area of crop diseases and their management.

In 2016, a new spatially explicit landscape-scale simulation model of breakdown in resistance to blackleg in canola was produced. The model was used to analyse how different factors drive breakdown of resistance, including the amount of resistant versus susceptible canola grown each year, the way that different resistance genes were deployed over time (rotation), and the degree of coordination of rotation strategy between different farms in the landscape.

Several relevant datasets on frequency of pathogen virulence alleles over time were analysed in various locations and under different conditions and selection regimes, in order to better understand the drivers and the underlying genetics of the evolution of pathogen virulence.

A new model for forecasting risk of virus epidemics in pea crops was also developed. Several approaches were considered, and finally an empirical/statistical approach





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that was most accurate and most suited to the practical requirements that the forecasting tool needed to satisfy was used to best inform crop virus real-time management decisions.

Work commenced on the final aim, to produce an analytical canopy-scale simulation model representing the progression of necrotrophic fungal diseases in cereals over a growing season, as influenced by seasonal weather conditions.

**This research is supported by the GRDC.**

**16 Caption:** Output of spatial simulation model of canola blackleg virulence evolution, showing disease severity across four fields with different histories of rotation of resistance genes.

## Innovative approaches to resistance to necrotrophic pathogens and sap-sucking insect pests

**Project team:** Adjunct Prof Karam Singh<sup>1,2</sup> (leader; karam.singh@csiro.au), Adjunct Assoc/Prof Jonathan Anderson<sup>1,2</sup>, Dr Louise Thatcher<sup>2</sup>, Dr Lingling Gao<sup>2</sup>, Dr Angela Williams<sup>1,2</sup>, Dr Gagan Garg<sup>2</sup>, Mr Nicholas Pain<sup>2</sup>, Ms Hayley Casarotto<sup>2</sup>, Ms Priya Krishnamurthy<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>CSIRO

Necrotrophic pathogens and insect pests cause substantial losses to legume crops each year.

This project focuses on identifying and understanding the molecular mechanisms of resistance to *Fusarium* wilt, *Rhizoctonia* bare-patch and root/hypocotyl rot and aphids in the model legume *Medicago truncatula*.

Genome analysis of *Fusarium oxysporum* and *R. solani* have identified novel mechanisms of pathogenesis, knowledge of which may be used to reduce susceptibility and improve management practices in crops. Legume genes and metabolites involved in resistance to these diseases and pests have been identified and are targets for future legume crop improvement.

**This research is supported by the GRDC and CSIRO.**

**17 Caption:** Screening a mutant *Medicago* population for altered resistance to *Fusarium* wilt. Photo: Louise Thatcher

## Design and Evaluation of Biosecurity Surveillance Systems

**Project Team:** Dr Michael Renton<sup>1</sup> (leader; michael.renton@uwa.edu.au), Dr Maggie Triska<sup>1</sup>, Assoc/Prof Benedict White<sup>1</sup>, Dr Jacky Edwards<sup>2</sup>, Dr John Wainer<sup>2</sup>, Dr Cassandra Collins<sup>5</sup>, Dr John Weiss<sup>2</sup>, Adjunct Prof Roger Jones<sup>1</sup>, Mr Andrew Taylor<sup>3</sup>, Dr Lloyd Stringer<sup>4</sup>, Dr Sarah Collins<sup>3</sup>, Dr Sonya Broughton<sup>3</sup>, Adjunct Prof Kevin Powell<sup>2</sup>

**Collaborating Organisations:** <sup>1</sup>UWA; <sup>2</sup>Department of Economic Development, Jobs, Transport and Resources Victoria; <sup>3</sup>DAFWA; <sup>4</sup>The New Zealand Institute for Plant and Food Research Limited (PFRNZ); Vinehealth Australia; <sup>5</sup>University of Adelaide

This project aims to develop general methods for designing and evaluating statistically-based surveillance systems for high priority horticulture threats. In 2016, we produced spread models with different surveillance strategy options, for three case studies; two arthropod pests, grape phylloxera (*Daktulosphaira vitifoliae* Fitch) and Mediterranean fruit fly (*Ceratitidis capitata*; Medfly) and one nematode pest, potato cyst nematode (*Globodera rostochiensis*; PCN).

In the grape phylloxera case study, field and modelling experiences were applied to create a local (within vineyard) spread model for phylloxera under varying soil conditions. This spread model, combined with multiple surveillance strategies, displays that targeting surveillance sampling towards highly-suitable soils in vineyards could significantly improve the speed of detection and minimise spread of new phylloxera incursion.

The Medfly model simulates pest dispersal at the scale of a town, or a portion of a city. Within the town, fruit trees, surrounding orchards and high risk invasion points (caravan parks, shopping centres) are identified. Initial results suggest that targeting high risk introduction sites and high fruit tree density areas could significantly improve the speed of detection and minimise the spread of new fruit fly incursions.

For PCN, a network model based on historic spread data was developed, the location of potato-growing regions and the number of potato-growing properties in each region to assess pest movement at both landscape and local scales. Properties based on production type and connectivity were classified and simulated surveillance under both property and area quarantine. Initial results suggest that surveillance may be improved through increases in survey number and targeting properties based on their location or distance to an invasion.

**This research is supported by the CRC for Plant Biosecurity.**

## Crop Genomics

**Project team:** Prof Dave Edwards<sup>1</sup> (leader; dave.edwards@uwa.edu.au), Prof Jacqueline Batley<sup>1</sup> (leader; Jacqueline.batley@uwa.edu.au), Philipp Bayer, Bhavna Hurgobin, Mahsa Mousaviderazmahalleh, Kenneth Chan, Jenny Lee, Andy Yuan, Armin Scheben, Habib Rijzaani

**Collaborating organisations:** <sup>1</sup>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.

Using a unique combination of isolated chromosome sequencing and skim-based genotyping by sequencing, the team have been able to assess, validate and improve draft assemblies for both of these genomes. Final assembled versions are being prepared for publication and release during 2017.

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

The genomics research has been extended to sequence the pangenomes of important crop species. The pangenome of *Brassica oleracea* was published in Nature Communications in 2016 and the pangenome of bread wheat has been accepted for publication.

**This research is supported by the ARC and the GRDC.**

## Plant information systems

**Project team:** Prof Dave Edwards<sup>1</sup> (leader; dave.edwards@uwa.edu.au), Kenneth Chan, Philipp Bayer

**Collaborating organisations:** <sup>1</sup>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.

The research team is working with international crop informatics consortia to promote collaboration and advancement in crop data management, from genomics through to breeding.



## Genetics and pre-breeding of wheat

**Project team:** Prof Guijun Yan<sup>1</sup> (leader; guijun.yan@uwa.edu.au); Dr Helen Liu<sup>1</sup>, Ms Olive Onyemaobi<sup>1</sup>, Mr Md Sultan Mia<sup>1</sup>, Ms Xingyi Wang<sup>1</sup>, Ms Roopali Bhoite<sup>1</sup>, Ms Fangning Zhang<sup>1</sup>, Ms Fabian Inturrisi<sup>1</sup>, Ms Fei Ren<sup>1</sup>, Mr Hafiz Bilal<sup>1</sup>, Dr Habtamu Tamir<sup>1</sup>, Dr Hameed Alsamadany<sup>1</sup>, Dr Jun Ma<sup>1</sup>, Dr Zhi Zheng, Hackett Prof Kadambot Siddique<sup>1</sup>, Dr Chunji Liu<sup>8</sup>, Prof Jacqueline Batley<sup>1</sup>, Prof Dave Edwards<sup>1</sup>, Prof Aimin Zhang<sup>2</sup>, Prof Yong Zhang<sup>3</sup>, Prof Zhanyuan Lu<sup>1</sup>, Prof Yong Wang<sup>4</sup>, Prof Haibo Wang<sup>5</sup>, Dr Shancen Zhao<sup>6</sup>, Dr Daniel Mullan<sup>7</sup>, Prof John Manners<sup>8</sup>, Prof Catherine Feuillet<sup>9</sup>, Prof Jinkao Guo<sup>10</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>CAS; <sup>3</sup>CAAS; <sup>4</sup>GAAS; <sup>5</sup>HAAFS; <sup>6</sup>BGI; <sup>7</sup>InterGrain; <sup>8</sup>CSIRO; <sup>9</sup>INRA; <sup>10</sup>SAAFS; <sup>11</sup>IMAAHS

Wheat is a major crop in Australia. Improved yield and quality is the primary goal of wheat breeding programs to address food security and sustainability. However, wheat is vulnerable to biotic and abiotic stresses and its yield production is highly dependent on the specific environment.

The Wheat Genetics and Pre-breeding Group focuses research on drought tolerance (Habtamu Tamir, Olive Onyemaobi and Md Sultan Mia), heat tolerance (Hameed Alsamadany), pre-harvest sprouting tolerance (Xingyi Wang), nutrient use efficiency (Hafiz Bilal), herbicide tolerance (Roopali Bhoite), disease resistance (Jun Ma, Zhi Zheng, Fei Ren, Fangning Zhang, and Fabian Inturrisi) and an accelerated population development system for pre-breeding (Helen Liu).

Major outcomes include newly developed near isogenic lines targeting major QTLs for heat tolerance, drought tolerance and pre-harvest sprouting tolerance. New and improved fast generation cycling systems (FGCS) and a complete in vitro FGCS protocol for wheat pure line production have been developed and used in wheat.

**This research is supported by the ARC, Yitpi Foundation and COGGO.**

**18 Caption:** Embryo culture for the fast generation cycling of wheat. The figure showed the germinated immature embryo on the medium.

## Genetic analysis of herbicide tolerance in bred wheat (*Triticum aestivum*. L.)

**Project team:** Ms Roopali Bhoite (PhD Candidate; roopali.bhoite@research.uwa.edu.au), Prof Guijun Yan, Dr Ping Si, Hackett Prof Kadambot Siddique

Weeds are a major external factor causing serious both yield and quality reduction in broad acre wheat production. Metribuzin (C<sub>8</sub>H<sub>14</sub>N<sub>4</sub>O<sub>5</sub>) is a Group C herbicide used to control a range of weeds, but it incurs moderate damage in majority of wheat cultivars. Higher tolerance to metribuzin is desired in new wheat varieties for improved weed management.

A clear understanding of the genetics and mechanism of metribuzin tolerance is vital for breeding metribuzin tolerance and developing new wheat cultivars. The International Triticeae Mapping Initiative (ITMI) population Synthetic W7984 × Opata M85, consisting of 115 recombinant inbred lines (RILs) was used to investigate QTLs involved in metribuzin tolerance.

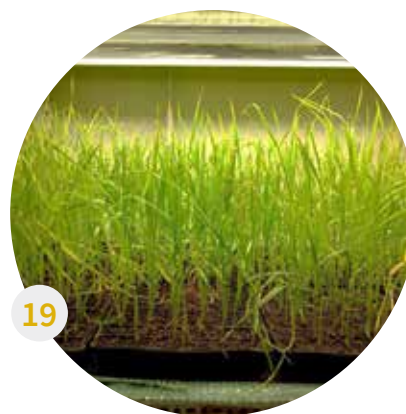
The population was evaluated in seedling tray (25×25×6 cm). Treatment and control trays were sprayed with pre-emergent metribuzin (400 g ai ha<sup>-1</sup>) and water respectively, perpendicular to the tray surface in two passes at a flowrate of 118 L ha<sup>-1</sup> and 200kPa pressure in a cabinet spray chamber.

The sprayed trays were placed in a cooled glasshouse, where the temperature was set to 25/15 °C day/night. The trays were watered every 48 h. The phytotoxic effects of metribuzin in wheat seedlings were recorded using a portable chlorophyll meter, 16 DAT.

The SPAD chlorophyll content index (CCI) scores was obtained from leaf lamina at 1/4th and 1/2th position from the leaf tip and the average reading taken from two fully emerged leaves represented the final score.

Foliar chlorosis/leaf senescence was visually estimated using a scale of 0 (no senescence/phytotoxicity) to 10 (100 per cent senescence/dead), 16 DAT. This count was defined as the senescence score (SS). The phenotypic score and marker data were combined to identify QTLs involved in metribuzin tolerance.

**This research is supported by an Australian Postgraduate Award.**



## Characterisation of drought tolerance in bred wheat using genetic and genomic tools

**Project team:** Prof Guijun Yan (leader; guijun.yan@uwa.edu.au), Mr Md Sultan Mia, Dr Hui Liu

Growing crops in adverse environmental condition has always been a challenge to the growers of Bangladesh, Australia and other parts of the world. Crop production is often hampered by a number of biotic and abiotic stresses like heat, drought, salinity and diseases. Among those stresses, drought is by far the most detrimental limiting the yield potential of a crop.

Previous studies have identified several major drought tolerance related quantitative trait loci (QTLs) in wheat, and some DNA markers linked to these loci have been reported. This study integrates some of the selected major QTLs to create a pyramiding population by utilising an embryo-culture based fast generation system and marker assisted selection.

The first experiment investigates the response of wheat to post-anthesis water stress, and the nature of gene action as revealed by combining ability analysis and has been completed. Near isogenic lines (NILs) targeting on each of the major QTL, and pyramid populations are being developed and they are in F<sub>6</sub> generation developed. Comparison of the expression profiles of mRNA and protein of each NIL pair under both stressed and non-stress environment will lead to the identification of genes/proteins associated with drought tolerance.

**This research is supported by an Endeavour Postgraduate Scholarship.**

**19 Caption:** Pyramid population (F<sub>3</sub>) under controlled environment.





## Exogenous application of brassinosteroids to maintain leaf photosynthesis in wheat under water deficit

**Project team:** Ms Victoria Figueroa Bustos (PhD Candidate; v.figueroabustos@research.uwa.edu.au), Hackett Prof Kadambot Siddique, Adjunct Prof Jairo Palta, Dr Yinglong Chen

Brassinosteroids (Brs) are phytohormones that play a crucial role in the control of numerous plant growth and developmental processes. Brs provide resistance to abiotic stresses such as drought and heat in several species through the alteration of several physiological processes including leaf photosynthesis.

The aim of this preliminary research was to determine the optimal dose of exogenous application of BR during reproductive stages to maintain flag leaf photosynthetic rate in wheat under water deficit.

The glasshouse experiment was conducted in 2016 using wheat cultivar Mace. Seeds were sown in PVC pots nine cm in diameter filled with soil to a depth of 40 cm. The experiment was arranged in a complete block design with two watering regimes, 11 Brs concentrations and five replicates. At 50 per cent awn emergence a Brs solution was sprayed onto the flag leaf, after this water deficit treatment was imposed in 50 per cent of the pots by withholding watering until permanent wilting of the flag leaf. Photosynthesis was measured with a gas exchange system at 3, 5 and 7 days of Brs application on the flag leaf.

The results showed that there were no interaction between water stress and brassinosteroids. There was a significant effect of water deficit on photosynthesis; decreased by 21 per cent, 87 per cent and 98 per cent at three, five and seven days after the drought treatment. However there was no significant differences between Brs dosages and photosynthesis at three, five and seven days after application. In conclusion, there was not effect of Brs on flag leaf photosynthetic rate in wheat in this study.

**This research is supported by CONICYT-BECAS, Chile.**

**20 Caption:** Wheat plants after five days of well-watered conditions.



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

**Project team:** Ms Xingyi Wang<sup>1</sup> (PhD Candidate; xingyi.wang@research.uwa.edu.au), Prof Guijun Yan<sup>1</sup>, Hackett Prof Kadambot Siddique<sup>1</sup>, Prof Zhiying Ma<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Agricultural University of Hebei, China

Pre-harvest sprouting (PHS) can cause severe damage to the quality and production of wheat, which is the major grain crop in Australia. PHS refers to the phenomenon that the unharvested wheat grains germinated or sprout on the plant in the field when they encounter rain or air-humidity close to saturation.

PHS is a lack of seed dormancy which is a quantitative trait regulated by several genes or QTLs and affected by environmental factors. Some of the important genes or QTL for PHS resistance has been consistently identified on the chromosome 3A, 4A and 4B.

To identify the specific genes for PHS resistance, this study aims to develop near-isogenic lines (NILs) using the closest makers to the QTL on 3A, 4A and 4B. An embryo-culture based fast generation system was used to shorten the wheat growth and development cycle.

A germination index was used to evaluate the phenotype of NILs. So far, five pairs, 16 pairs and ten pairs of NILs for 3A, 4A and 4B, have been developed respectively. Transcriptome analysis will be done on those NIL pairs to identify the major genes responsible for PHS resistance.

Diallel analysis is a powerful tool for investigating genetic properties. In this project, parents of NILs, including DM5637B\*8 (PHS resistant), SUN326AE (PHS resistant), Westonia (PHS susceptible) and Chara (PHS susceptible), were crossed with reciprocals to produce 4×4 full diallel sets. F1 generation was planted in a glasshouse and harvested at physiological maturity.

Germination tests will be done both on the harvested seeds and on the spikes to assess the PHS resistance. The combining ability will be calculated according to the data analysis, which will give a comprehensive understanding of the genetics of PHS.

**This research is supported by the Yipti Foundation.**

**21 Caption:** NIL population (F<sub>7</sub>) in the UWA glasshouse.



## Phenotyping root traits in wheat germplasm

**Project team:** Hackett Prof Kadambot Siddique (leader; kadambot.siddique@uwa.edu.au), Dr Yinglong Chen

Root architectural traits influences nutrient and water uptake efficiency. Root traits that overcome abiotic and biotic constraints are critical to maintaining root length, function, and water capture. However use of root-related traits in breeding is hampered by relatively small mapping populations and inaccurate phenotyping.

Development of future wheat cultivars with enhanced drought resistance and increased water-use and nutrient efficiencies are critical for improving wheat adaptation and yield in dryland environments. The aim of this study was to characterise root-related traits in a diverse set of wheat germplasm in order to understand the role of root systems in improving yield and productivity.

A large phenotyping experiment involving 187 wheat genotypes from 139 countries were carried out using the novel semi-hydroponic platform. Wide variation in root system architecture across wheat germplasm tested was identified. Over 30 root-related traits were characterised, and comprehensive analyses on trait-to-trait correlations, root and shoot trait relationship were also performed.

For the first time, wheat genotypes with vastly different root properties were identified for further studies ultimately aimed at developing germplasm with root traits for improved adaptation to specific environments.

**22 Caption:** Wheat plants grew in semi-hydroponic phenotyping system for characterising root growth.

## Optimising crop root systems to enhance capture of soil water and nutrients

**Project team:** Prof Zed Rengel<sup>1</sup> (leader; zed.rengel@uwa.edu.au), Dr Yinglong Chen<sup>1</sup>, Dr Jidong Wang<sup>2</sup>, Dr Vanessa Dunbabin<sup>3</sup>, Dr Arthur Diggle<sup>4</sup>, Prof Guihua Bai<sup>5</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Jiangsu Academy of Agricultural Sciences, China; <sup>3</sup>Bangor Farm, Australia; <sup>4</sup>DAFWA; <sup>5</sup>Kansas State University, USA



Barley (*Hordeum vulgare* L.) is an important versatile crop, but its sustainable production is hampered by different abiotic stresses. Characterising the variability in root architecture in barley lines would provide the basis for breeding new germplasm with suitable root traits for improved adaptation to specific environments.

In 2016, a phenotyping experiment conducted in the UWA glasshouse using the established semi-hydroponic phenotyping system characterised root phenome traits in a 189-line association mapping population.

Results showed diverse variation in rooting patterns among the tested lines. Twenty-six root-related traits were analysed, 16 of which had significant variation among lines with coefficients of variation greater than 0.25. The Pearson correlation matrix exhibited strong correlations among most of the selected root traits ( $P \leq 0.05$ ). Principal component analysis revealed three principals with eigenvalues  $>1$  capturing 72 per cent of total variation. Eight lines with contrasting key root traits, including root mass, total root length, root depth, etc., were selected for further testing in soil columns with two types of soil. Root data collected from the soil experiment confirmed ranking orders in some root traits among the eight lines.

The next step will use association and linkage mapping to identify molecular markers associated with specific root traits characterised in this study. Root data acquired in this study can be used to parameterise root structural and functional models such as ROOTMAP to simulate root growth and reconstruction of root system.

The eventual aim of this project is to breed barley cultivars with root properties for efficient water/nutrient acquisition and for enhanced adaptation to drought and other edaphic stresses.

**This research is supported by the ARC.**

**23 Caption:** Visiting research fellow Dr Jidong Wang of Jiangsu Academy of Agricultural Sciences, China examines plant growth in a UWA glasshouse.



24

## Effect of salinity on P acquisition by wheat genotypes differing in salt tolerance

**Project team:** Hackett Prof Kadambot Siddique<sup>1</sup> (leader; kadambot.siddique@uwa.edu.au), Dr Ghulam Abbass<sup>2</sup>, Dr Yinglong Chen<sup>1</sup>, Adjunct Prof Jairo Palta<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Department of Environmental Sciences, Pakistan

Soil salinity is one of the major abiotic stresses which reduces plant growth and productivity. It is estimated that six per cent of the world's land and 30 per cent of the world's irrigated areas are suffering from salinity problem. Likewise, about 30-40 per cent of the world's arable lands has very low productivity due to P deficiency. The P deficiency becomes more severe when crops are grown on calcareous salt-affected soils.

To investigate the interactive effects of salinity and low P on physiological and root morphological attributes, a rhizobox experiment was conducted using two wheat cultivars Janz (salinity tolerant) and Jandaroi (salinity sensitive) in a temperature-controlled glasshouse at UWA.

At two-leaf stage, salt stress (100 mM NaCl) was applied with optimal (100  $\mu$ M) and low P (10  $\mu$ M) treatments alone as well as in combination. 40 days after sowing, the plants were harvested and their growth attributes were recorded. The roots recovered from each 10-cm section were scanned for root growth attributes. Salinity and low P reduce plant growth by affecting leaf area, leaf water content, and gas exchange attributes, and reduction in K and P uptake.

The effect of low P was more detrimental than salinity and the interaction of both stresses was not additive. The detrimental effects of salinity and low P become prominent on root growth after 20 days of stress. The effects of various stressed root growth were more prominent in upper soil layer than lower layers.

**This research is supported by Endeavour Fellowship.**

**24 Caption:** Dr Ghulam Abbas tracing root growth of wheat plants affected by salinity and low P stresses.



25

## Pre-breeding of canola

**Project team:** Prof Wallace Cowling<sup>1</sup> (leader; wallace.cowling@uwa.edu.au), Ms Jasenka Vuksik<sup>1</sup>, Ms Roz Ezzy<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>NPZ Australia Pty Ltd; NPZ Lembke, Germany; <sup>3</sup>University of New England (UNE)

A new method of crop breeding based on the animal model has been developed. Recent work with colleagues in animal breeding and quantitative genetics at UNE Armidale shows that traditional genetic progress in crop breeding, with yield improvements less than one per cent per year, could be doubled with the aid of optimal contribution selection. This report included the first use of optimal contribution selection (OCS) for breeding of self-pollinated crops. OCS can result in improvements in long-term genetic gain while minimal inbreeding.

Typically, selfing crops lose genetic diversity as a result of crossing after selfing and selection of pure lines; but the new approach evaluates early generation lines and promotes these to crossing, based on best linear unbiased prediction (BLUP) of breeding value for yield and other complex traits, combined into an economic index of genetic value in \$/ha. BLUP or genomic BLUP values can be estimated for drought and heat-stress tolerance, grain yield and quality, and predictions are improved by integrating data across cycles of selection. This change in crop breeding methods is motivated by the need to improve response to selection, including genomic selection, for grain yield in the face of global climate change.

The new crop breeding method is being applied to great advantage in our commercially-funded canola pre-breeding project, and continue researching and publishing improvements in the method.

**This research is supported by NPZ Australia Pty Ltd.**

**25 Caption:** Genetic diversity in flowering time in the NPZ Australia Pty Ltd canola pre-breeding project at UWA.





## International Research Support Initiative Programme

**Project team:** Prof Guijun Yan (leader; guijun.yan@uwa.edu.au), Mr Hafiz Muhammad Bilal, Dr Tariq Aziz, Dr M Aamer Maqsood, Dr Hui Liu

At the middle of this century the world population will increase to over nine billion and the food requirements will increase 70-100 per cent. Increasing yield is the only option to ensure food security.

Advances in molecular marker technology over the past decade have led to the development of detailed molecular linkage maps. These linkage maps have allowed the dissection of quantitatively expressed traits into Mendelian factors referred to as quantitative trait loci (QTLs), each linked to molecular markers of a known map position.

Phosphorus (P) is one of the major limiting factors for the production of wheat crop. The detection of putative QTLs represents a crucial first step that could eventually lead to the identification of genes controlling P uptake and P-use efficiency or to the identification of tightly linked markers to be used in marker-assisted selection. This would be an alternative approach to develop future crops that are more efficient at acquiring inorganic P (Pi) from soil and/or at using P more efficiently.

The seeds of 88 inbred lines (F8) along with their parents were used in this study. Two seeds were sown in each polythene lined pot filled with 5.8 kg washed river sand. Half strength Hoagland nutrient solution was used to maintained moisture contents at 75 per cent field capacity to supply with nutrients and to avoid anaerobic condition, respectively. The nutrient solution was supplied three times per week. After 50 days of sowing one plant from each pot was harvested and divided into young leaves, older leaves and stem. All samples were divided into two aliquots: material from one plant was immediately stored at  $-80^{\circ}\text{C}$  for genetic and free Pi analysis, while material from the other two plants was placed in oven at  $60^{\circ}\text{C}$  for drying.

**This research is supported by the Higher Education Commission, Pakistan.**

**26 Caption:** One plant from each pot was harvested after 50 days of sowing. Photo: Mr M Azam Khan

## Novel use of antitranspirants to improve wheat yield in the grainbelt of WA

**Project team:** Dr Ken Flower (leader; kenneth.flower@uwa.edu.au), Dr Imran Malik, Hackett Prof Kadambot Siddique.

It is well known that low and variable rainfall significantly reduces crop yield in WA, especially when it occurs during flowering and grainfill. There is recent evidence that film antitranspirants, applied at booting to flowering in wheat, can significantly improve grain yield of wheat suffering from drought.

The aim of this research was to determine if film antitranspirants used in this way (applied later in the growth – booting to flowering) could significantly improve wheat yield under WA field conditions, with dry finishes (terminal drought). Two antitranspirant products were applied at two different times (booting and flowering) under field conditions at Cunderdin, Merredin and Southern Cross in 2016. The antitranspirant increased the yield of wheat significantly ( $P=0.039$ ) at Merredin, from  $2235\text{ kg ha}^{-1}$  in the untreated control to  $2560\text{ kg ha}^{-1}$  (about 15 per cent). The timing of the application had no effect. Unfortunately frost severely impacted the trials at Cunderdin (average yield of about  $1400\text{ kg ha}^{-1}$ ) and Southern Cross (average yield of  $742\text{ kg ha}^{-1}$ ) and no differences between treatments were observed.

**This research was supported by COGGO.**

**27 Caption:** Water-stressed wheat.



28

## Improving yield by optimising energy use efficiency

**Project team:** Prof Harvey Millar<sup>1</sup> (leader; harvey.millar@uwa.edu.au), Dr Nicolas Taylor<sup>1</sup> (leader; nicolas.taylor@uwa.edu.au), Dr Elke Stroeher<sup>1</sup>, Mr Ting Tang<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Australian National University (ANU); <sup>3</sup>The University of Adelaide; <sup>4</sup>CIMMYT, Mexico

The International Wheat Yield Partnership (IWYP) was established to contribute to a G20 nations plan to strengthen future, global food security. The issue of global food security was highlighted by The Food and Agriculture Organization of the United Nations who have identified that global crop yields must double by 2050 to meet future needs. To address this need Agriculture Ministers of the G20 nations established IWYP, a unique, international funding initiative to coordinate 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 per cent.

This project, which commenced in 2016, is one of only eight internationally to be selected for funding through IWYP. As the Australian partner of IWYP, the GRDC will be the primary funder of this project.

UWA researchers from the ARC Centre of Excellence in Plant Energy Biology and the UWA School of Molecular Sciences form part of a team of Australian scientists that have been selected to address a key component of a global future food security solution by increasing the energy efficiency of wheat.

More than 85 per cent 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 the 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 2016, members of the team visited CIMMYT in Obergon and made measurements of photosynthesis and respiration in 300 elite wheat varieties and collected plant material for analysis of proteins and metabolites by mass spectrometry. At the same time researchers at UWA developed the necessary analysis pipelines and tools require to prepare, analyse and interpret the results of the mass spectrometry.

**This research is supported by the International Wheat Yield Partnership and the GRDC.**

**28 Caption:** Using an Astec Global Q2 for the high throughput measurement of respiration of wheat plants in the lab. Photo: James Campbell Photographics

## Phosphorus acquisition efficiency and phosphorus utilisation efficiency in the chickpea germplasm

**Project team:** Hackett Prof Kadambot Siddique<sup>1</sup> (leader; kadambot.siddique@uwa.edu.au), Dr Jiayin Pang<sup>1</sup>, Prof Hans Lambers<sup>1</sup>, Assoc/Prof Megan Ryan<sup>1</sup>, Dr Ruchi Bansal<sup>2</sup>, Dr Hongxia Zhao<sup>3</sup>, Mr Emilien Bohuon<sup>4</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>National Bureau of Plant Genetic Resources, India; <sup>3</sup>Chinese Academy of Sciences; <sup>4</sup>UniLaSalle, France; <sup>5</sup>ICRISAT

As 70 per cent of global cultivated land suffers from Pi deficiency and low use efficiency of P fertiliser (often < 30 per cent) due to chemical immobilisation of P and agricultural run-off, improvements in crop nutrition to maximise phosphate acquisition efficiency (PAE) and phosphate utilisation efficiency (PUE) are urgently needed for future food production.

Chickpea is the second most important grain legume (pulse) globally, and is the largest pulse crop in Australia, currently grown on over 0.5 million ha (FAOSTAT, 2014). The identification of chickpea genotypes with high P acquisition and/or internal P utilisation efficiency is important for the breeding programs to reduce P input while maintaining the yield of chickpea in low-P input farming systems.

The objectives of this project were to assess the genotypic variation in PAE among 266 chickpea accessions from the world reference collection imported from ICRISAT, India and some standard Australian cultivars under low-P conditions, and to understand the physiological mechanisms underlying low-P tolerance in chickpea.

The preliminary results from the glasshouse showed that among 266 chickpea genotypes, shoot and root growth had an 8-fold and 30-fold variation, respectively. Shoot P concentration and shoot P content showed a 6-fold and 7-fold variation, respectively. P efficiency ratio, defined as the ratio of shoot DW to shoot P content, had a 5-fold variation, while physiological P use efficiency, defined as the ratio of shoot DW to shoot P concentration, showed a 30-fold difference among



266 genotypes. Shoot P concentration was found strongly correlated with shoot and root dry weight, total root length, root surface and rhizosphere carboxylate exudation.

Further research is currently underway to identify the physiological and molecular basis of P acquisition efficiency and P utilisation efficiency in chickpea.

**29 Caption:** Glasshouse study involving the screening of 266 chickpea reference set with diverse genetic background from 29 countries for phosphorus use efficiency.

## The sensitivity of different *Lupinus* species to pH and bicarbonate under low-phosphorus supply

**Project team:** Prof Hans Lambers<sup>1</sup> (leader; hans.lambers@uwa.edu.au); Ms Wenli Ding<sup>1</sup>, Dr Peta Clode<sup>2</sup>, Dr Jon Clements<sup>2</sup>

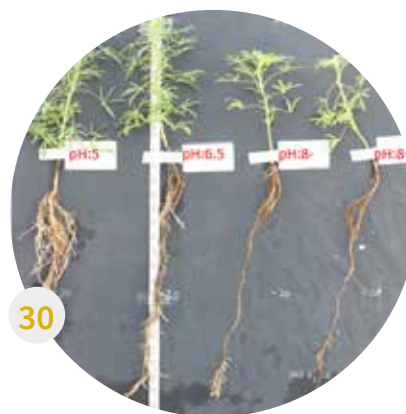
**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA

*Lupinus* species respond differently to calcareous soils, which are characterised by a low availability of phosphorus (P) and several micronutrients, including iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu); most of them prefer acid soils, while some prefer calcareous soils. The mechanism behind the calcifuge habit of some *Lupinus* species, especially under low-P conditions, is still unclear.

In 2016, the sensitivity of different *Lupinus* species to calcium (Ca) under a low-P supply was assessed. Ca does play an important role in the calcifuge habit of *Lupinus* species; however, there are also other factors involved. Therefore in 2016, research focused on pH.

Four *Lupinus* species (6 genotypes, *L. angustifolius*-cv Mandelup, *L. angustifolius*-wild-01, *L. angustifolius*-wild-02, *L. angustifolius*-wild-03, *L. cosentinii* and *L. pilosus*) were grown hydroponically under four levels of pH and bicarbonate supply (a: 5; b: 6.5; c: 8-; d: 8. +), these wild *L. angustifolius* were collected from soil site with pH of 5, 6.5 and 7.5 separately. The pH was checked three times per day, and a, b, c were adjust by KOH and buffered with MES and TES (0.5 M) at the same time, d was adjusted by K<sub>2</sub>CO<sub>3</sub> without any buffer added.

Gas exchange, leaf area, cluster-root formation and biomass were measured; leaf and root nutrient concentrations (including P and Ca) and the leaf cell types in which Ca



and P accumulated were also determined using elemental X-ray microanalyses. Based on the biomass data, leaf symptoms and gas exchange measurements, pH toxicity was demonstrated for almost all the genotypes, except *L. pilosus*.

The results obtained in this experiment almost completely agree with *Lupinus* species' natural occurrence, for example, *L. angustifolius* cv Mandelup is sensitive to calcareous soils, while *L. pilosus* is tolerant of calcareous soils. Both root and shoot growth of *L. angustifolius* were inhibited by high pH, and it is worthwhile to mention that root surface disintegration of *L. angustifolius* under high pH was observed, and formation of lateral roots in all species was decreased by high pH, with *L. pilosus* showing the least affected level.

All of these results suggest that pH is the main cause of *Lupinus* species' sensitivity to calcareous soils and fine roots may play a very important role in pH tolerance of calcicole *Lupinus* species.

**This research is supported by the ARC.**

**30 Caption:** The growth of *L. angustifolius* cv under different levels of pH.



## Phosphorus-efficient legume pasture systems (UWA module)

**Project team:** Assoc/Prof Megan Ryan<sup>1</sup> (leader; [megan.ryan@uwa.edu.au](mailto:megan.ryan@uwa.edu.au)), Dr Richard Simpson<sup>1,2</sup>, Mr Graeme Sandral<sup>3</sup>, Mr Daniel Kidd<sup>4</sup>, Dr Richard Culvenor<sup>2</sup>, Prof Hans Lambers<sup>1</sup>, Dr Phillip Nichols<sup>1,4</sup>, Dr Richard Hayes<sup>3</sup>, Mr Robert Jeffery<sup>4</sup>, Prof Martin Barbetti<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>CSIRO; <sup>3</sup>NSW DPI; <sup>4</sup>DAFWA

As phosphorus (P) reserves diminish and prices of phosphorus fertilisers rise, it will become necessary to develop more P-efficient farming systems. This project focuses on southern Australia's major annual pasture legume, subterranean clover (*Trifolium subterraneum*).

This project aimed to prove that highly productive pasture systems can be operated with substantially less phosphorus (P)-fertiliser by using plants with low 'critical' P requirements, and quantify (benchmark) the critical P requirements of key pasture legume species relative to subterranean clover. It also aimed to identify the root morphology traits that have the largest influence on the critical P requirements of subterranean clover and alternative legume species and assess the variation in P-efficient root traits of subterranean clover and quantify the potential for breeding P-efficient clovers. A clear decision point for breeding improved subterranean clovers, and/or evaluation of alternative legume species for P-efficient farming systems would be developed with improved environmental credentials for grazing industries with respect to efficiency of fertiliser use, reduced over-application, and less loss of P to the wider environment.

The project successfully identified annual pasture legumes with a greater capacity to access soil P than the current widely-grown species, subterranean clover. Most notable for superior P uptake were species of serradella (*Ornithopus*).

The project also showed that among the annual pasture legumes the key root trait associated with a superior capacity to capture soil P, and hence a low external critical P requirement, is a large root hair cylinder volume. For instance, for the serradellas, abundant long, thin roots with long root hairs enabled a large root hair cylinder volume. In contrast, subterranean clover had relatively thick roots and short root hairs.

The project concluded that serradella species have an ability to capture soil P similar to that of grasses. Consequently, in situations where serradellas are well adapted, serradella pastures based on current cultivars should be able to produce high yields whilst fertilised to maintain a Colwell P lower than that required for subterranean clover.

Further work is required to determine how to improve the adaptation of serradella, especially in eastern Australia, and how to improve the capacity of subterranean clover to take up phosphorus from soil.

**This research is supported by MLA and Australian Wool Innovation Ltd.**



**31 Caption:** Sampling pastures in the field to determine root characteristics.

## Phosphorus efficient pastures: delivering high nitrogen and water use efficiency, and reducing cost of production across southern Australia

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

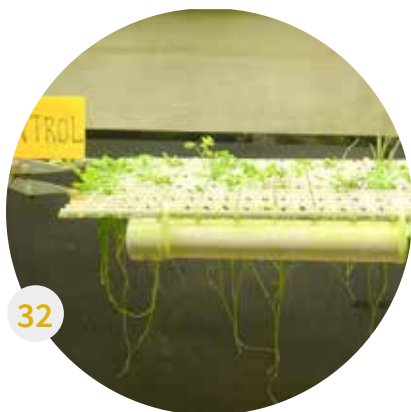
**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>CSIRO; <sup>3</sup>NSW DPI; <sup>4</sup>Murdoch University

The project aims to reduce the phosphorus (P)-dependence of Australian temperate pastures through expanding the use of high yielding pasture legumes that have lower P requirements than subterranean clover (*Trifolium subterraneum*). It builds upon previous work by this research team that identified serradella species (*Ornithopus*) as better able to access soil P than subterranean clover.

The project aimed to (i) quantify responses of three serradella species to key stresses potentially limiting the serradella adaptation range (cold, waterlogging, and aluminium and manganese toxicities); (ii) explore serradella phenology; and (iii) develop molecular tools for breeding P-efficient subterranean clover using genome wide association studies within the subterranean clover core and elite cultivar collections.

The project commenced in mid-2016. Field sites in eastern and western Australia were selected for the farmer group experiments and weed control implementation. The UWA component commenced with a screen in hydroponics for tolerance of high aluminium. Past and present serradella cultivars were included which together constituted 13 yellow serradellas, 15 French serradellas, 1 slender serradella and 1 hybrid serradella along with high aluminium-sensitive burr medic, lucerne and subterranean clover, and acid soil-tolerant phalaris (cv. Advanced AT).

**This research is supported by the Department of Agriculture and Water Resources through its Rural Research and Development for Profit program, MLA, AWI and Dairy Australia**



**32 Caption:** Screening in hydroponics for tolerance of aluminium.

## Flowering genes in lupins

**Project team:** Ms Candy Taylor<sup>1</sup> (PhD Candidate; candy.taylor@research.uwa.edu.au), Prof Wallace Cowling<sup>1</sup>, Dr Matthew Nelson<sup>2</sup>, Dr Lars Kamphuis<sup>3</sup>, Dr Jens Berger<sup>3</sup> and Dr Jonathan Clements<sup>4</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Kew Botanic Gardens, UK; <sup>3</sup>CSIRO; <sup>4</sup>DAFWA

Australian narrow-leaved lupin varieties have limited diversity for phenological traits, including flowering time. Since the national breeding program was established in the 1960s, only three variants for flowering time (named Ku, ku and efl) have been selected. This has resulted in two distinctive and widely separated phenotypic groups. The first of these is early flowering and vernalisation-insensitive; the result of Ku. It is the largest group, well adapted to the warmer northern WA growing regions, and contains the most elite varieties. The second phenotypic group is the result of ku or efl, and is characterised as a vernalisation-responsive, late-season group adapted only to the southern WA and in eastern Australia.

In order to expand the Australian lupin industry, it will be increasingly important for the national breeding program to introduce new phenological diversity to fill the divide between these two flowering time groups. For example, a vernalisation-insensitive narrow-leaved lupin with later flowering than current Ku varieties would enable higher yield potential in years with longer seasons, particularly in WA. Additionally, such a phenotype could alleviate harvesting difficulties associated with early maturity (such as low harvest height) and balance the acceleration to flowering anticipated with increases in mean temperature.

To address this issue, our research team is conducting a genome wide association study (GWAS) to identify genetic flowering time variation (QTLs; quantitative trait loci) in 388 narrow-leaved lupin accessions, including wild types from the Mediterranean region and domestic lines from Australian and European breeding programs. In addition, we will be screening LanFTc1 as the gene underlying the Ku/ku locus, to determine whether other gene sequence variants (i.e. alleles) exist.



In 2016, we began phenotyping the flowering date for over half of our panel under fully saturating and mild vernalisation treatments. These two treatments will enable us to detect vernalisation responsive QTLs and thermal time to flowering QTLs, respectively. Preliminary analysis of the phenotypic data is extremely exciting, with a staggering breadth to flowering time in wild Greek material. Early Greek and Israeli accessions have a unique flowering trait – they flower just a few days after the Ku genotype in both the presence and absence of vernalisation. This could be a valuable trait for improved adaptation and yield of lupins in southern Australia.

**This research is supported by the GRDC and DAFWA.**

**33 Caption:** Wild narrow-leaved lupin plants flowering. Image: Candy Taylor

## Exploring scope for new crop suitability at Marvel Loch, Western Australia

**Project team:** Hackett Professor Kadambot Siddique<sup>1</sup> (leader; kadambot.siddique@uwa.edu.au); Prof Tim Colmer<sup>1</sup>; Adjunct Prof Chris Johansen<sup>1</sup>, Mr Courtney Piesse<sup>3</sup>, Mr Andrew Farson<sup>3</sup>; E/Prof John Taplin<sup>2</sup>, Dr Ying Jiang<sup>2</sup>, Ms Joy Taplin<sup>2</sup>, Mr Michael Wang<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Virtue Australia Foundation; <sup>3</sup>Elders Rural Services

In July 2016, Emeritus Professor John Taplin and UWA researchers embarked on a project to examine new crop possibilities for farmlands located at Marvel Loch, on the eastern fringe of the WA grain belt. In particular, there was interest from Chinese collaborators in scope for growing castor for export to China.

A team from Virtue Australia, Elders and IOA reconnoitred the location in September and noted that there would be little possibility for irrigation, a prerequisite for castor cultivation in this marginal, winter rainfall environment. An agroclimatic analysis revealed an increase in summer rainfall over time, raising possibilities of summer cropping, but this rainfall was too variable and remained too low, in relation to demands of evapotranspiration, to reliably support summer crops to maturity. However, there may be some scope for cultivation of short duration fodder sorghum or millets, to supplement summer livestock feed.



Winter rainfall has been declining over time, however, which poses particular challenges to the existing marginal rainfed, wheat-pasture farming system. To enhance this system, there is a need to introduce short duration, drought tolerant cereal varieties, suitable for late planting, and potential wheat, barley and oat varieties were suggested. There is a need to diversify cropping and potential grain legume varieties, of chickpea, field pea and lupin, and also canola, were proposed. The pasture phase could also be improved by incorporation of pasture legumes, to improve animal nutrition and soil carbon and nitrogen status. Suitable varieties of subterranean clover, medics, serradella, bisurella and vetch were proposed. There are also options for inclusion of native forage species and some tree crops adapted to semi-arid conditions.

To manage risk in this declining and increasingly variable rainfall environment, in addition to introducing suitable crop and pasture varieties, it is necessary to adopt rainfall responsive agronomic procedures. Weather forecasting becomes increasingly important for optimising sowing time in a particular season. The major soil constraints at the site are acidity, salinity and low soil organic carbon resulting in poor soil physical characteristics.

Introduction of legume crop and pasture species would contribute to a build-up of soil organic carbon, as well as improve the nitrogen economy of the system. The fertilizer application regime should be rationalised according to the nutrient needs of particular crops, and better match top dressing of nitrogen to the rainfall pattern. Strategies are also suggested for managing ryegrass, a valuable forage grass, but a crop weed prone to herbicide resistance.

Only if reliable and economically viable sources of fresh water can be identified, to permit at least some supplementary irrigation, could the region diversify from the traditional rainfed crop-pasture system. However, options are available to meet the challenges of declining rainfall patterns in an already marginal rainfall environment, by increasing the flexibility of varietal choice and agronomic management.

**This research is supported by Virtue Australia Foundation.**

**34 Caption:** The team (L to R): Courtney Piesse, Ryan Neilson, Kadambot Siddique, John Taplin, Joy Taplin, Ying Jiang and Tim Colmer, examining a wheat crop at Marvel Loch. Photo: C. Johansen

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## The agronomic and economic impact of no-tillage on WA dryland agriculture

**Project team:** Mr Bill Crabtree (PhD Candidate; [william.crabtree@research.uwa.edu.au](mailto:william.crabtree@research.uwa.edu.au)), Dr Ken Flower, Hackett Prof Kadambot Siddique, Dr James Fogarty

No-tillage is a tool that has enabled sustainable cropping in erosion-prone and dry environments and it has improved the sustainability of WA farm practices. Farmers cropping in the dry WA environment have rapidly adopted the no-tillage system and now the state is considered a world leader with virtually complete adoption. This was made possible by the advent, and farmers' acceptance, of knockdown herbicides to kill weeds rather than with tillage. The change was successful due to the persistent efforts of farmers and the agricultural industry who were determined to solve problems with no-tillage. There are many lessons to be learnt from this experience, in a global context, to aid in further adoption of no-tillage.

This study will, initially, document these revolutionary changes, and challenges that had to be overcome, to ensure a high and stable no-tillage adoption rate in the cropping landscape in WA. A paper on the history and birth of direct drilling and minimum tillage from the period of 1963-1990 is almost complete. This paper highlights the challenges and changes that were needed for this technology to mature to a level where no-tillage could be successfully adopted.

A second paper chronicles and discusses the rapid adoption of no-tillage technology. Adoption of this technology is now greater than 95 per cent across wheatbelt in WA and this has led improved reliability and level of crop production, which otherwise may have dwindled.

The next step in the study is to determine the agronomic and economic value of no-tillage to WA farmers.

**This research is supported by the ARC.**

**35 Caption:** Keynote speaker Bill Crabtree talks to AAPRESID Argentinian No-Tillage Farmers Association on the challenges of implementing cover crops in the dry WA Wheatbelt in August 2016.



## A long-term study to increase water use efficiency, grain yield and the profit of growers in the western region in a no-tillage system

**Project Team:** Dr Ken Flower<sup>1</sup> (leader; [kenneth.flower@uwa.edu.au](mailto:kenneth.flower@uwa.edu.au)), Neil Cordingley<sup>2</sup>, Dr David Minkey<sup>2</sup>, Dr Phil Ward<sup>3</sup>, Mr Shayne Micin<sup>3</sup>, Mr Nathan Craig<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA, <sup>2</sup>WANTFA, <sup>3</sup>CSIRO

The trial was started in 2007 and is based at the WA College of Agriculture, Cunderdin. It was initially set up to assess if maintaining high levels of crop residues could boost crop productivity, grain production and profits in no-till systems. The focus has changed slightly and now it is investigating the agronomic and economic costs and benefits of using crop residue retention, diverse rotations, minimal soil disturbance and controlled traffic (reduced compaction) tactics over time in a no-tillage system. It is also comparing the effect of full residue retention (high residue) and windrow burning (low residue — for weed seed control).

The 2016 yields were significantly reduced by frost and this affected the results.

Over the longer term, windrow burning reduced residue levels by 40-66 per cent at seeding. Levels of canola residue had little effect on following wheat yield. By contrast, when the amount of cereal residue carried over at seeding was high (e.g. with high yields the previous year), the reduction in residue caused by windrow burning had a positive effect on wheat yield. This effect was likely due to difficulties seeding through the heavy residues and also reduced herbicide efficacy and increased stubble borne diseases. Conversely, when the cereal residue levels at seeding were relatively low, further reducing the amounts by windrow burning had negative effect or no effect. The increased yield with fully retained (spread) residues, when pre-seeding residue levels were relatively low, was thought to be due to increased water conservation.

Continuous wheat and cereal rotation (mainly wheat and barley) had the highest cumulative 9-year average gross margins, despite the diverse rotation (wheat–legume–canola) showing higher grain protein concentration in most years and improved wheat yield over time. Lower gross margins in the diverse rotation were associated with poor legume performance in many years and low canola yields in dry seasons. Cover crops in the rotation negatively impacted gross margins, without any observed yield benefits in the following years.

**This research is supported by the GRDC.**

**36 Caption:** Windrow burning in canola.

# Fate of pre-emergence herbicides intercepted by residues in conservation agriculture systems

**Project team:** Mr Yaseen Khalil<sup>1</sup> (PhD Candidate; yaseen.khalil@research.uwa.edu.au), Dr Ken Flower<sup>1</sup>, Hackett Prof Kadambot Siddique<sup>1</sup>, Dr Phil Ward<sup>2</sup>, Dr Colin Piggin<sup>3</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>CSIRO; <sup>3</sup>ACIAR

Pre-emergent herbicides are applied to the soil and many require some incorporation. However, these herbicides can be intercepted by stubble, which may reduce weed control in no-tillage (NT) cropping systems. As stubble retention is a key component of NT systems in Australia, it is important to understand the factors, such as stubble and rainfall, which influence the efficacy of pre-emergent herbicides in WA.

This research has two main objectives: (i) to determine effect of rainfall on leaching of trifluralin, pyroxasulfone and prosulfocarb from stubble, and (ii) to investigate effect of amount of crop residue and its moisture content on retention and leaching of trifluralin, pyroxasulfone and prosulfocarb.

Experiments included three commonly used pre-emergent herbicides (trifluralin, prosulfocarb, pyroxasulfone) in southern Australia applied at recommended rates, different rainfall (amount, timing, intensity), and different crop residue treatments (amount, moisture condition). Four petri dishes, each with 50 g of dry soil, were placed onto plastic seedling trays, then covered by crop residue and sprayed with herbicides.

In the first experiment, the trays were covered with wheat residue equivalent to 4t ha<sup>-1</sup>. Then, simulated rainfall applied with four amounts (0, 5, 10, or 20 mm), three different intensities (5, 10, or 20 mm hr<sup>-1</sup>) and five times (0, 0.25, 1, 7, or 14 days after spraying herbicides).

In the second experiment, herbicides applied over the 4t ha<sup>-1</sup> of residue and this was followed by four simulated rainfall treatments with an amount of 20 mm at 10 mm hr<sup>-1</sup> intensity: no rainfall, four 5 mm rainfall events over two days, two-10 mm rainfall events over one day, single 20 mm rainfall event.

In the third experiment, an equivalent of 4t ha<sup>-1</sup> (measured dry) of wet or dry wheat residue was placed over plastic trays followed by the herbicide sprays, then 20 mm of simulated rainfall (at the same intensity as trial two) was applied.

In the fourth trial, different amounts of wheat residue representing 0, 1, 2, 4t ha<sup>-1</sup> were placed on the trays followed by the herbicide sprays and the same 20 mm of rainfall or no rainfall. Bioassays were developed to assess the availability of herbicide in the soil and remaining on the residue, using two indicator plants (cucumber, ryegrass). Shoot length of the plants was measured and the inhibition effect of the tested herbicides expressed as a percentage of the untreated control; where less inhibition with the crop residue indicated more herbicide was leached from the residue into the soil.



Crop residues intercepted herbicides during application. Some of the herbicide washed off the residue with as little as 10-20 mm of rainfall. The sooner the rainfall occurred the greater the amount of herbicide leached. There were no differences between rainfall intensities. Multiple rainfall events of five-mm over two days (total of 20 mm) leached less herbicide from the residue into the soil compared with a single 20 mm event.

Less herbicide leached from crop residue after rainfall, when chemicals were applied to initially wet residue, rather than dry residue. Increased amounts of wheat residue intercepted more herbicide, with a large increase in interception from two to four t/ha. However, 100 per cent of ryegrass was controlled with pyroxasulfone after rainfall, even with 4 t/ha, indicating that this herbicide was still effective in high stubble loads following rainfall. Trifluralin was the least effective in high stubble loads.

**This research is supported by ACIAR John Allwright Fellowship.**

**37 Caption:** Simulation of different rainfall amounts at different rainfall intensities. Photo: Yaseen Khalil

## Characterisation of soil microbial interactions for increased efficacy of herbicides using novel fertiliser management practices

**Project team:** Prof Andy Whiteley<sup>1</sup> (leader; andy.whiteley@uwa.edu.au); E/Prof Lynette Abbott<sup>1</sup>, Dr Abul Hashem<sup>3</sup>, Mr Paul Storer<sup>1</sup>, Dr Vivek Bhat<sup>2</sup>, Dr Zakaria Solaiman<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Australian Mineral Fertilisers; <sup>3</sup>DAFWA

This project started in 2015 and is investigating bio-physical interactions associated with herbicide efficacy in agricultural soils. The three aims of this research are: (i) to determine whether herbicide efficacy can be maximised in cropping systems specifically managed for enhanced microbially mediated ecosystem services, (ii) to determine whether a change in herbicide mode of action aimed at managing weed (ryegrass) populations that have developed resistance to an existing mode of action is mirrored by changes in soil microbial community structure and function, and (iii) to determine the impact of herbicides on microbial diversity and function in soils managed using novel fertiliser practices.





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This involves understanding the efficacy of herbicides in soils managed for increased reliance on soil biological fertility, modes of interactions between mineral fertilisers and herbicides in the rhizospheres of resistant and susceptible ryegrass, and the relationship between herbicide group and pattern of microbial degradation of herbicides in soil.

A field trial was established at York, WA in 2016. The aim of this trial is to determine whether herbicide efficacy can be maximised in soils specifically managed for increased dependence on microbial processes associated with nutrient use efficiency and water use efficiency in cropping systems. There were six treatments including glyphosate alone and in combination with four other herbicides (Glean, sakura, MCPA and Bromoxynil) and a nil treatment, with either mineral-based fertiliser or chemical fertiliser.

Another glasshouse experiment was conducted to determine the impact of pre-emergent herbicides on soil microbial diversity and function managed using mineral fertiliser practices. There were five herbicide treatments including four herbicides (simazine, atrazine, sakura and glean) and a nil treatment, with mineral-based fertiliser and chemical fertiliser.

In another field experiment and a parallel pot experiment, we investigated the effects of a mineral fertiliser containing six levels of phosphorus in comparison with standard chemical fertilizer (district practice) on plant traits and P utilisation efficiency for wheat. This study has been completed and a manuscript is being finalised.

**This research is supported by the ARC.**

**38 Caption:** A field trial was established at York, WA in 2016. Photo: Dr Zakaria Solaiman



## Spatial temperature measurement and mapping tools to assist management of frost risk at farm scale: Rapid assessment of damage in wheat after frost

**Project team:** Dr Steven Crimp<sup>1</sup> (Leader; [steven.crimp@csiro.au](mailto:steven.crimp@csiro.au)), Dr Ken Flower<sup>2</sup>, Dr Nik Callow<sup>2</sup>, Dr Bryan Boruff<sup>2</sup>, Ms Bonny Stutsel<sup>3</sup>, Ms Mary Murphy<sup>2</sup>, Mr Mick Fulkner<sup>3</sup>; Ms Kirsten Barlow<sup>4</sup>, Ms Eileen Perry<sup>4</sup>, Mr Glenn Fitzgerald<sup>4</sup>, E/Prof Hamlyn Jones<sup>2,5</sup>

**Collaborating organisations:** <sup>1</sup>CSIRO, <sup>2</sup>UWA, <sup>3</sup>Agrilink, <sup>4</sup>Victorian Department of Economic Development, Jobs, Transport and Resources (DEDJTR), <sup>5</sup>University of Dundee, Scotland

Extreme weather events, such as frost, are already a significant challenge for grain producers and are predicted to increase under future climate scenarios. Recent statistics for frost related damage in Australia estimated agricultural losses at between \$120 m and \$700 m each year.

Frosts that occur during or after ear-emergence can often result in severe stem and head damage, which can reduce grain yields and quality by up to 80 per cent, depending on location, altitude, soils and the severity of the frost.

However, other than visually assessing a crop 5 to 7 days after a frost event, there are no tools available to determine if a frost has occurred and to map the extent of the damage it has caused. Farmers would benefit greatly if they could obtain quasi real time information about frosted wheat paddocks that are likely to have yield losses. For example, decisions on inputs or when and how much of the crop to cut for hay could then be made. Maps of frost damaged areas of the paddock would also help farmers at harvest time as frosted areas of the paddock could be left unharvested if necessary, thereby reducing costs.

The aim of this project was to develop methods to rapidly assess frost damage in wheat. Both proximal and remote sensing methods will be tested using ground- (or hand-held), UAV- (RPAS) or satellite-based sensors.

The 2016 activities provided good initial data and showed the potential for some of the sensors tested to detect changes in the plant in response to frost. The measurements highlighted some of the priorities for the next season in further testing these approaches and refining the data analysis. Design and deployment of frost exclusion chambers continues to be a challenge and modified techniques will be tested in 2017. Preliminary data analysis indicates several sensor measurement types respond to differences in frost treatment.



Continued analysis will assess candidate measurement types (e.g. a specific reflectance or fluorometer index), and evaluate the 'robustness' of the measurement type with respect to: (i) detection of symptoms of frost damage before they become visual, and response over time following a frost event; (ii) differences across varieties and; (iii) differences in scale (plant component level (wheat leaf or head versus canopy) and the nominal resolution or field of view required.

**This research is supported by the GRDC National Frost Initiative.**

**39 Caption:** PhD students Bonny Stutsel and Mary Murphy setting up the field experiments.

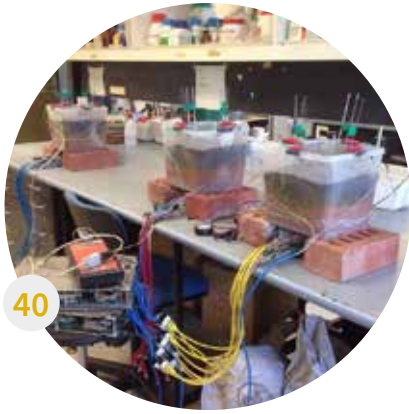
## Soil water repellency: Limitations on water infiltration and its spatial distribution attributing to loss of agricultural productivity

**Project team:** Ms Mary-Anne Lowe<sup>1</sup> (PhD Candidate; [mary-anne.lowe@research.uwa.edu.au](mailto:mary-anne.lowe@research.uwa.edu.au)), Dr Matthias Leopold<sup>1</sup>, Dr Gavan McGrath<sup>1</sup>, Dr Falko Mathes<sup>1</sup>, Dr Meng Heng Loke and Prof Daniel Murphy<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>CRC for Polymers

Soil water repellency is a naturally occurring limitation on infiltration, effecting multiple land uses around the world, most notably effecting agricultural land uses in southern Australia. In Western Australia alone around five-million hectares are at risk of water repellence and around \$250 million is forfeited each year in the agricultural industry.

The research we are conducting looks at an innovative combination of shallow geophysics to understand fundamental processes of breaking down water repellence. This will be relevant for many fields of soil science and agriculture, but also has specific relevance to broad acre agriculture within a large area of southern Australia.



2016 saw the setup and trialling of electrical resistivity tomography in an arrangement of boreholes to give a 3D map of water distribution within the boundaries of the boreholes, allowing imaging without any disruption of the soil mapping area. The experiment is set up with a water repellent core surrounded by wetting soil. With the application of water in a rainfall pattern we can observe the wetting of the core under different treatments including chemical and biological treatments.

After the wetting of the core we have been sampling and drying the soil at 40 degrees for an extended period of time to see the longer lasting effects of the treatments on water repellency and their possible causes.

**This research is supported by CRC for Polymers and a University Postgraduate Award.**

**40 Caption:** Borehole ERT boxes in the lab.





# 2 Sustainable Grazing Systems

## Theme leaders:

**Professor Graeme Martin**, [graeme.martin@uwa.edu.au](mailto:graeme.martin@uwa.edu.au)

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The Sustainable Grazing Systems theme looks at the sustainable contribution of livestock industries to global food supply. The focus is on resolving five key problems. These are:

- i) the consumption of human food by livestock
- ii) livestock species and genotypes that are poorly adapted to the local environment
- iii) poor animal health and welfare resulting in sub-optimal productivity
- iv) provision of adequate animal nutrition and
- v) the environmental footprint.

The main grazing systems include extensive rangeland systems and mixed crop-pasture systems.

Rangeland systems are extensive, low-input and predominantly cattle-based, with a smaller but valuable goat and sheep sector. The interest in the 'emerging north' of Australia is driving discussion of this system.

Mixed crop-pasture systems in 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, to continue providing feed for the various animal-production systems in Western Australia.

Research undertaken in this theme has contributed to the crop-pasture and animal-production nexus, conducted in close cooperation with other national and international Research, Development, Extension and Adoption (R,D,E and A) partners.





## Methane-fighting forages

### Transitioning to resilient perennial pasture systems to abate greenhouse gases and sequester carbon

**Project team:** Dr Julian Hill<sup>1</sup> (leader; upweyag@optusnet.com.au), Prof Phil Vercoe<sup>1</sup>, Gonz Mata<sup>3</sup>, Dr Joe Jacobs<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Victoria DPI; <sup>3</sup>CSIRO; Ternes Agricultural Consulting

This project compares the potential for abatement of production of greenhouse gases (methane and nitrous oxide) and sequestration of carbon, using perennial legumes and shrubs in a ryegrass base. The advantages over the business-as-usual ryegrass-only systems are being demonstrated, showing how producers can transition to a low-emissions system while improving productivity.

A long-term farming systems trial was undertaken in Eastern Gippsland, Victoria to determine if systems change (incorporation of legumes and perennial shrubs) resulted in a change in total emissions and emissions intensities of sheep production.

The overall impact of legume addition to the ration is being assessed in terms of the contribution it could make to national inventory. The incorporation of legumes into the systems is also being assessed in terms of the effects on soil carbon sequestration, and compared with business-as-usual practice.

The plant secondary compounds associated with perennial shrubs have the potential to reduce total emissions and emissions intensity, and the data in this study is currently being analysed to establish whether these compounds reduced daily emissions and emissions intensity, and whether there were effects on rates of growth of the sheep.

**This project is funded by the Australian Government's Department of Agriculture.**

**1 Caption:** Animals transitioning to new grazing system.



## Host control of methane emissions from sheep

**Project team:** Prof Phil Vercoe<sup>1</sup> (leader; philip.vercoe@uwa.edu.au), Dr Hutton Oddy<sup>2</sup>, Prof Roger Hegarty<sup>3</sup>, Prof Stephen Moore<sup>4</sup>, Dr Brian Dalrymple<sup>5</sup>, Dr Stuart Denman<sup>5</sup>, Mr John McEwan<sup>6</sup>, Prof Noelle Cockett<sup>7</sup>, Prof John Wallace<sup>8</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>NSW DPI; <sup>3</sup>University of New England; <sup>4</sup>University of Queensland; <sup>5</sup>CSIRO; <sup>6</sup>AgResearch, New Zealand; <sup>7</sup>Utah State University, USA; <sup>8</sup>University of Aberdeen, UK

Ruminant methane emissions are a product of microbial fermentation, with the host animal influencing microbial populations by feed choice and through morphological/functional variation in its fore-stomachs. There is evidence that these functions are heritable through the host.

The aim of this project is to generate new insights into the fundamental biology of variation in rumen function and methane emissions in sheep, by measuring in detail host phenotype (methane emissions, rumen size and morphology, digesta flow rate) and linking this to host genotype (imputed genome sequence), transcriptome (RNA sequence, species identification) of the gastro-intestinal tract, and the metagenome of the rumen microbial population.

The team has established that the rate of flow of digesta from the rumen and rumen volume are the major gross physiological factors contributing to natural variation in methane production and the yield of methane per amount of feed eaten in sheep. For the first time the team has demonstrated that the rumen is derived as an outgrowth of the oesophagus and is not closely related to the small intestine of monogastric animals, and that gene expression in the rumen wall of animals differing in methane yield differs at the level of cell cycle activity.

When the ruminal microbiome was examined in the animals, the results were consistent with other recent reports from cattle and sheep and provide preliminary evidence that a repeatable 'core' microbiome in sheep is related to methane production. Using the more repeatable microbes as indicators of variation in rumen methane production is encouraging (accuracy of prediction ~0.2). The team also identified novel associations between the ruminal microbiome and metabolites, particularly between methyl donor compounds, betaine and proline betaine, which are known precursors for methylamine production.

Several potential chromosomal regions that linked to key traits were identified, but the team was unable to locate specific genes responsible for variation in methane production. It is likely that such variation is affected by many genes that influence rumen function (and feeding behaviour). This indicates that genome-wide tools, such as those used in Genomic Breeding Values, may be the short-term genomic path to inclusion of methane traits in breeding programs.

The associations between these host genes and methane emissions will be explored further across all of the RNA sequencing data that has been generated from sheep flocks in New Zealand and Australia. Sequence information about the microbial populations in the rumen of these animals has been collated and is currently being analysed and interpreted to establish the links between the gene expression in the host, its phenotype and the microbiome in the rumen.

**This project is funded by the Australian Government's Department of Agriculture and MLA.**

**2 Caption:** Sheep being scanned for rumen volume.

## Understanding the bioactivity of the forage legume *Biserrula pelecinus* L. – variability and mechanisms

**Project team:** Mr Bidhyut Banik<sup>1</sup> (PhD candidate; bidhyut.banik@research.uwa.edu.au), Prof William Erskine<sup>1</sup>, Dr Zoey Durmic<sup>1</sup>, Dr Joy Vadhanabhuti<sup>1</sup>, Prof Phil Vercoe<sup>1</sup>, Dr Clinton Revell<sup>2</sup>, Dr Chris McSweeney<sup>3</sup>, Mr Jagadish Padmanabha<sup>3</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA; <sup>3</sup>CSIRO

Annual forage legume *Biserrula pelecinus* L. (biserrula) offers an exciting prospect as a bioactive plant, because it results in seven to ten times less methane than other forage legumes when fermented *in vitro* by rumen microbes. There was a critical need to progress knowledge on the nature of this anti-methanogenic effect, as well as how it might be influenced by various plant and environmental factors.

This research was conducted as part of Mr Bidhyut Banik's PhD studies and focused on investigating the mechanism(s) of the anti-methanogenic property of biserrula, to understand how different types of plant stress (physiological and environmental) affect the activity of this pasture species towards rumen microbes.

In total, seven *in vitro* experiments were conducted to examine effects on fermentation, microbial ecology and persistency of the anti-methanogenic bioactivity.

Exploration of the mechanism of anti-methanogenic bioactivity was conducted through fractionation of plant extracts and testing these fractions against pure cultures of key rumen methanogens. This was followed by batch and continuous culture experiments that evaluated the persistency of biserrula over time and when mixed with



subterranean clover. Finally, persistency of the bioactivity was tested when plant was exposed to nutritional and physiological stresses.

The key findings are that the anti-methanogenic bioactivity of biserrula persists over time, and/or when mixed with another plant (subterranean clover), in vegetative and reproductive growth stages, and when the plant was defoliated or exposed to a gradient of soil phosphorus (P).

It was also shown that the plant was targeting methanogens directly, because a significant reduction in total methane production occurred without hampering key fermentation parameters in a continuous culture system. This effect was also confirmed in pure culture, where the bioactive fractions from biserrula reduced methane production and cell growth of the main rumen methanogens. Chemical profiling indicated the presence of flavonoid glycosides as a major component of these fractions.

It was also revealed that the influences of plant stress on anti-methanogenic bioactivity in this plant were limited. The physical damage of biserrula via defoliation at the reproductive stage reduced methanogenic potential *in vitro*. However, only one genotype of biserrula, 2004ERI1PEL, showed a decrease in methanogenic potential at a P level of 96 mg P/kg in the soil, while two other genotypes showed no change. While there was some genotype effect within biserrula for methanogenic potential in response to these stressors, this was small compared to the species effect (i.e. the comparison with subterranean clover). All biserrula treatments consistently produced higher anti-methanogenic bioactivity compared with subterranean clover, regardless of the genotype, stage of growth or type of stress.

Overall, the research showed the effectiveness and consistency of the anti-methanogenic bioactivity of biserrula and that the effect is reliant on specific chemical compounds within the plant that target rumen methanogens. Stresses imposed on the plant do not markedly reduce the potency of the anti-methanogenic bioactivity of biserrula. These results offer encouragement for further experimentation (i.e. *in vivo*) to assist the development of grazing strategies and potentially novel plant-based feed additives to manipulate enteric methane production.

**This research is supported by the Federal Government's Department of Agriculture and a CSIRO PhD Top-Up Scholarship.**

**3 Caption:** Measuring the antimethanogenic properties of biserrula *in vitro*.







# Investigating Indonesian forages for their potential to reduce methane emission while increasing the productivity in local ruminants

**Project team:** Prof Phil Vercoe<sup>1</sup> (leader; philip.vercoe@uwa.edu.au), Ms Amriana Hifizah<sup>1</sup>, Prof Graeme Martin<sup>1</sup>, Prof drh Muhammad Hambal<sup>2</sup>, Dr drh Reza Ferasyi<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>University of Syiah Kuala, Indonesia

Methane emitted by industrial ruminants is an important contributor not only to global warming but also to a loss in production potential because the animals are losing up to 10 per cent of their metabolic energy. Importantly, in Australia, we are now discovering ruminant-edible forages that contain plant secondary compounds, which can reduce methane synthesis.

Both aspects of the methane problem – the greenhouse gas emissions and the energy inefficiency – are directly relevant to Indonesia, a developing agricultural country with a population growth rate of one per cent per annum and with a rapidly increasing demand for ruminant products such as meat and milk. We therefore need to find ways to improve the carbon footprint of livestock production in Indonesia by investigating local forage species for their potential to mitigate methane emissions.

Indonesian forage plants have not been systematically studied for their potential to reduce methane production. Several local forage species plants, however, are known to produce bioactive compounds or secondary metabolites that can be anti-pathogenic or anti-inflammatory, such as *Ageratum conyzoides*, *Annona muricata* L. and *Moringa oleifera*. Indeed, compounds from these plants have been used as traditional medicine for both humans and ruminants.

In 2016, we interviewed ruminant nutritionists, government field officers, and goat farmers in Banda Aceh province. These people provided background information for 41 local plant species from Banda Aceh that have traditionally been fed to goats, or could be fed to goats as alternative forages. We also screened records and previous studies about these species for information about secondary compounds, nutritive values and toxicity. This process allowed us to select 21 plant species for further study of their effects on methane production and rumen fermentation *in vitro* (batch culture and RUSITEC). Of particular interest are: *Pennisetum purpureum*; King grass; *Setaria decumbens*; *Calliandra calothyrsus*; Kudzu grass; *Sesbania grandiflora*; *Imperata cylindrica* Div; *Leucaena leucocephala*; *Calopogonium*; *Centrosema pubescens*; *Pterocarpus indicus*; *Gliricidia sepium* and *Brachiaria humidicola*.

When this first part of the project is completed, we will have further reduced the number of plants of interest and then be able to begin nutritive-value analysis.

**This research is supported by an Indonesian Endowment Fund for Education LPDP.**

# International coordination of the Ruminant Pangenome Project

**Project team:** Prof Phil Vercoe<sup>1</sup> (leader; philip.vercoe@uwa.edu.au); Dr Hutton Oddy<sup>2</sup>, Dr Chris McSweeney<sup>3</sup>, Prof Andrew Thompson<sup>4</sup>, Prof Roger Hegarty<sup>5</sup>, Dr Julian Hill<sup>6</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>NSW DPI; <sup>3</sup>CSIRO; <sup>4</sup>Murdoch University; <sup>5</sup>University of New England; <sup>6</sup>Ternes Agriculture Company; EU Framework <sup>7</sup>Ruminomics project; Utah State University, USA; AgResearch, New Zealand

The Ruminant Pangenome Project (RPP) has been developed to coordinate a collaborative Australian and international research network that will build on current research undertaken through the Reducing Emissions from Livestock Research Program (RELRP) and the National Livestock Methane Program (NLMP), and to deliver effective and practical strategies for reducing enteric livestock methane emissions while maintaining productivity.

The RPP comprises five projects: four research projects with an emphasis on the genetic control of methane emissions plus this project to coordinate the research, which is described here. The coordination project integrates research and development activities across all research providers and then synthesises research findings.

The research undertaken confirmed that variation in feed intake, rumen volume, distribution of digesta components and mean retention time are the likely sources of variation in methane yield between animals. This observation suggests that there is a genetic basis for differences between animals in methane yield. The project provides the first demonstration that rumen coordination (gut morphology x physiological processes x feed intake) is central to methane production, reflecting on the point that the experiments undertaken were designed to specifically interrogate these interactions.

The RPP provides compelling evidence that aspects of the biology of methanogenesis is controlled by the host animal, and that proactive management of the animal can result in management or abatement of methane production. The results will assist in the selection of robust and resilient genotypes to match the environment in which they are managed. They will also contribute to breeding strategies to mitigate methane emission by outlining the traits that are associated with variation in methane emissions. These insights will lead to new ways of selecting animals with natural variation in ingestive, digestive and metabolic processes that ensures that the nexus between methane production and animal efficiency is understood and managed.

It is unlikely that there is a single major gene family that is involved in regulating variation in methane traits. The heritable variation observed is likely to be conferred by many major gene families, and one area of major importance is the expression of genes controlling cell cycling in the rumen wall and the metabolism of volatile fatty acids. This observation provides a practical insight into new strategies to feed the

animal – for instance, the design of feed supplements that target and alter rumen function (e.g. via manipulation of butyrate-related pathways).

Furthermore, the observations that the animal coordination of the ruminal microbial community (and especially the repeatability in microbial consortia) means we can now account for significant variation in methane yield between animals. This opens several avenues to selecting low-methane sheep through the development of selection programs that use combinations of methane measurement and genotyping, together with variation in microbial composition.

The results from this program provide new opportunities for producers to improve their livestock by breeding, and provide insights about how a change in nutrient supply can be used to reduce methane emissions and improve productivity.

**This project is funded by the Australian Government's Department of Agriculture and MLA.**

## Genetics of breeding for breech strike resistance

**Project team:** Prof Phil Vercoe<sup>1</sup> (leader; philip.vercoe@uwa.edu.au), Mr Joseph Steer<sup>1</sup>, Adj/Prof Johan Greeff<sup>2</sup>, Assoc/Prof Gavin Flematti<sup>1</sup>, Res/Prof Shimin Liu<sup>1</sup>, Dr Tony Schlink<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA

Global wool production – and specifically wool production in Australia – is hindered by diseases and the changing nature of consumerism. One of the major diseases affecting wool sheep in Australia is breech flystrike (or cutaneous myiasis), which results in a substantial annual loss to the industry.

This situation triggered a research focus into the development of alternative flystrike control methods that are clean, green and ethical. The favoured alternative is selective breeding, and Australian Wool Innovations Ltd (AWI) is funding a large project that aims to identify effective indicator traits, which could be used to select indirectly for breech strike resistance. One of the indicator traits of interest is odour.

The most exciting outcome from this work has been the realisation of how fundamental an understanding of blowfly behaviour is in solving this issue. A number of important aspects of blowfly behaviour have been discovered, including the chemical, physical and visual cues that attract them to a site/bait, what determines whether they lay eggs or not, and the size of the clutch of eggs laid.

These findings are critical in developing the best strategies for solving the challenge of flystrike through breeding programs and potentially through more direct management, based on our understanding of why the flies are attracted in the first place and why they then decide to lay their eggs. Laboratory-based tests have been developed that enable us to manipulate fly behaviour and identify specific compounds



that stimulate the fly antennae. These are extremely powerful tools for developing solutions to flystrike.

We now know that *Lucilia cuprina* can choose between wools with different moisture levels and which have an optimum content for laying eggs. We also know that there is an odour, tactile and visual components in the attractiveness of a bait for gravid flies and that some of these also enable the flies to determine the size of the egg clutch.

Having developed the tests and knowing how to manipulate fly behaviour, the research is at an exciting stage because it has changed our thinking about what might be key drivers in determining resistance of susceptibility to flystrike.

**This project is funded by AWI.**

**5 Caption:** Electroantennogram is used to measure response of flies to different compounds.

## Innovative livestock and pasture systems to adapt to climate change and reduce methane emissions

**Project team:** Prof Phil Vercoe<sup>1</sup> (leader; philip.vercoe@uwa.edu.au), Dr Andrew Thompson<sup>2</sup>, Dr Peter Hutton<sup>1,2</sup>, Dr Stephanie Muir<sup>3</sup>, Ms Beth Paganoni<sup>4</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Murdoch University, <sup>3</sup>DPI Victoria, <sup>4</sup>DAFWA

Climate change presents two major challenges to extensive sheep production systems in southern Australia. First, methane from enteric fermentation in ruminants contributes about 13 per cent of Australia's emissions of greenhouse gases. Second, the advent of reduced rainfall during the growing season reduces the productivity of traditional pastures.

Sheep that graze legumes often produce less methane than when grazing grasses, which is most likely due to the legumes' lower content of structural carbohydrates (fibre) and the higher digestibility. These characteristics lead to a faster passage rate of food through the rumen.

Introduced legumes, including biserrula and French serradella, have desirable characteristics including hard seeds





and drought resistance, which make them ideally suited to ley farming systems in WA. These legumes are more likely than ryegrass to persist into late spring or early summer. However, legume pastures are lower in productivity during winter than ryegrass and difficult to maintain in a grass-based sward. Therefore, improved grazing systems that feature the introduction of novel legumes into grass-based systems may provide farmers with the opportunity to maintain or increase profitability in a changing climate.

We have demonstrated that sheep produce less methane from some pasture species than others. *Biserrula* reduces methane emissions more than other legumes when fed to animals in the animal house and this effect was greater when fed as fresh pasture compared to hay.

Testing different legumes in the laboratory reflected the results in the animal house, but a significant direct reduction in methane emissions in the field was not found. The most consistent key driver of methane and animal productivity in this project was pasture quality. High-digestibility and low-fibre feed reduced methane yields and methane intensity and increased productivity.

There is some evidence that a 'choice' pasture can improve rumen efficiency compared to ryegrass pasture alone, which was reflected in higher daily live weight gains in the sheep, but not in methane intensity. In addition, legume-based pastures provide an option to increase growth rates and decrease total methane emissions and emissions intensity during a period when perennial ryegrass pastures are declining in nutritive value.

The greatest challenge has been to demonstrate the differences we predicted from the laboratory and animal-house experiments in grazing animals. The variability in timing of grazing and grazing behaviour of animals prior to measurement may well be masking the differences that exist in the field. The results show that farmers should be able to make better choices of pasture species to reduce emissions and emissions intensity in grazing livestock without reducing productivity, but that it is difficult to demonstrate the effects on methane emissions in-field.

The clearest message for producers and policymakers is emphasising the importance of managing pastures and grazing techniques to maintain the highest quality of feed, because it improves rumen efficiency and animal productivity and ultimately improves emissions intensity. We are confident that the different effects that pasture species are having on

methane emissions are real, but more work needs to be done in the methodology around determining those effects in-field.

**This research is supported by the Australian Government's Department of Agriculture and MLA.**

**6 Caption:** Sheep grazing on *biserrula*.

## Duty of care: investigating the effects of novel forages on reproduction in sheep

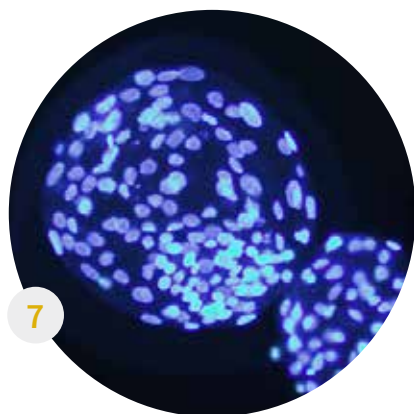
**Project team:** Prof Graeme Martin<sup>1</sup> (leader; [graeme.martin@uwa.edu.au](mailto:graeme.martin@uwa.edu.au)), Ms Anna Aryani Amir<sup>2</sup>, Assoc/Prof Dominique Blache<sup>1</sup>, Dr Zoey Durmic<sup>1</sup>, Dr Jennifer Kelly<sup>2</sup>, Dr Dave Kleeman<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>SARDI

Within ruminant livestock industries, there is increasing interest in alternative forages that can provide green feed in autumn (the breeding season) while also contributing other benefits such as reductions in methane emissions, gastro-intestinal worms and salinity. However, history warns us that we must test for unwanted side-effects if we are to avoid a repeat of the 'clover disease' of the 1950s, when the national sheep herd suffered massive infertility caused by a phyto-oestrogen, a plant secondary compound that interferes with the reproductive system.

Assessment of reproduction in grazing animals is difficult so we have decided to develop an approach based on in vitro fertilisation to screen new forages. To validate this approach, we are testing the effects of the well-known phyto-oestrogens of clover (genistein, biochanin A, formononetin) on sheep eggs obtained from the abattoir. The eggs are allowed to mature, then they are fertilised and the resulting embryos allowed to develop in culture. We record the success of fertilisation and embryo development, finally counting all the cells in each embryo. This process is followed in the presence of various concentrations of phyto-oestrogen (0, 2.5, 5, 10, 25 µg mL<sup>-1</sup>). The lower concentrations seem to have little effect, but the highest concentration decreases fertilisation and embryo development.

It is therefore likely that ingestion of forage containing large quantities of phyto-oestrogen could disrupt fertility and early embryo development in sheep. More broadly, we now have a system for testing the effects of plant secondary compounds that will allow us to screen new forages rapidly and thus fulfill our duty of care to the sheep industry.



**This research is supported by the Mike Carroll Travelling Fellowship, and UWA Postgraduate Research Travel Award.**

**7 Caption:** A 'hatching' blastocyst showing the cells of the embryo emerging from within the zona pellucida.

## Brain Regulation of Reproduction: Challenging the 'KNDy' Hypothesis

**Project team:** Prof Graeme Martin<sup>1</sup> (leader; graeme.martin@uwa.edu.au), Dr Jeremy Smith<sup>1</sup>, Dr Stacey Rietema<sup>1</sup>, Dr Penny Hawken<sup>1</sup>, Dr Chris Scott<sup>2</sup>, Prof Michael Lehman<sup>3</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Charles Sturt University; <sup>3</sup>University of Mississippi, USA

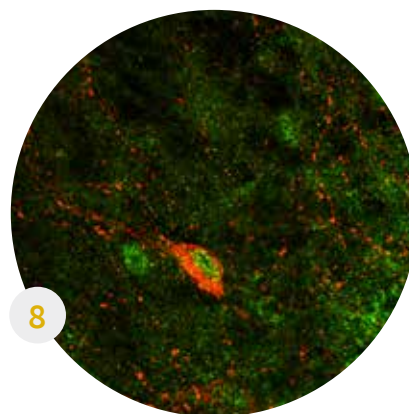
The brain switches reproduction on and off by changing the frequency with which it releases pulses of gonadotrophin-releasing hormone (GnRH). The processes responsible for the pulsatile signal have been a puzzle for decades, but recently brain cells that produce three peptides (kisspeptin, neurokinin B, dynorphin), known as 'KNDy cells', have been heralded as the 'missing link', or even the 'pulse generator'.

Using male and female sheep, we have been challenging the KNDy hypothesis with pheromones and with acute increases in nutrition, two factors that rapidly increase the frequency of GnRH pulses.

In the first experiment, rams that were given a lupin supplement on top of their normal ration were studied. Their KNDy cells were activated at the same time as the frequency of their GnRH pulses increased, within six hours of being fed the supplement.

In the second experiment, the 'female effect', in which rams show an increase in the brain GnRH signal within minutes of exposure to mature ewes, was studied. If the KNDy cells are responsible for the female effect, they should be activated; the brain tissues of the rams in this study are currently being analysed.

The third experiment is based on the 'male effect', or 'teasing', a common tool for controlling the timing of reproduction in Merino sheep. Ewes show a rapid and robust GnRH response upon exposure to novel males, resulting in ovulation during spring and early summer, normally the non-breeding season. We are attempting to block the male effect, with synthetic



analogues of neurokinin B and dynorphin. This experiment was done at Charles Sturt University in December 2016 and the blood samples will be processed during 2017.

**This research is supported by an ARC Discovery Project grant.**

**8 Caption:** Brain tissue from a ram in the 'female effect' experiment. Large bright green areas indicate the nuclei of cells that have recently been activated. The cytoplasm of GnRH cells is red, so where we have a cell that is red plus green, we have a GnRH activated by the ewe pheromone.

## Pastures in Australia's dryland agriculture regions

**Project team:** Adjunct Prof Ann Hamblin (leader; ann.hamblin@uwa.edu.au), Assoc/Prof M. Farooq, Hackett Prof Kadambot Siddique

This project formed the basis of a review chapter in the recently published volume "Innovations in dryland agriculture", cited above. The work identified the current condition and productive capacity of dryland (rainfed) pastures across the Intensive Land-use Zone or agricultural belt that lies between latitudes 23 and 41 degrees S, and contains 95 per cent of sheep and 55 per cent of cattle in Australia.

Following the collapse of the wool market in 1992, changes in the relative value of wool, meat and grains resulted in lower cash receipts from sheep and cattle enterprises. This led to a reduction in the productive capacity of many pastures, with less investment in re-seeding, fertiliser, liming and grazing management. Across all regions, in national surveys carried out in 1997 and 2011, 30 to 60 per cent of pastures were rated as poor or in decline.

Nevertheless, by 2014 pastures still occupied twice the area of crop land on Australian farms (50 million hectares compared with 22 million hectares of rainfed cropland), accounting for 70 per cent of farm land in the 300-600mm rainfall zone and more than 90 per cent in high rainfall zones. The lower productivity of many pastures compared with crops can constitute a significant under-utilization of capital resource, although native pastures, which form the larger extent in eastern Australia, are seldom capable of achieving the biomass production of exotic mixtures.

Recovery after the Millennium drought (2002-10) and increasing demand for both beef and lamb from Asian markets in the past five years have improved the opportunities for re-investment in pastures. Farmers are able to draw on extensive research and development done in the past 20 years on exotic pasture legume improvement and information technologies in management software, remote sensing and electronic monitoring.

Since 2010 there has also been substantial rationalisation of finishing (in feedlots), and processing (a reduction from 15 to two major companies since 2003) in the meat industry. At present many animal-dominated family farms are too small to take advantage of the economies of scale from these structural changes and need alternative marketing and management structures, such as cooperatives, to remain profitable. However larger farms and vertically-integrated production-processing and marketing systems point the way to more productive use of pastures in the future.

**Publication of this research was supported by Springer International Publishing.**







# 3 Water for Food Production

## Theme Leaders:

**Adjunct Professor Keith Smettem**, [keith.smettem@uwa.edu.au](mailto:keith.smettem@uwa.edu.au)

**Assoc/Prof Matthew Hipsey**, [matthew.hipsey@uwa.edu.au](mailto:matthew.hipsey@uwa.edu.au)

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. The Water for Food Production theme focuses on improved efficiencies in irrigated agriculture and better use of finite water resources to meet the food needs of an increasing world population.

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, optimisation of on-farm water use for maximum return, and minimisation of 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.

The Water for Food Production theme comprises research on water balance and irrigation modelling, and environmental sensing and assessment, with a strong focus on industry collaboration and engagement, postgraduate training and technology exchange.



# Impact of water allocation strategies to manage groundwater resources in Western Australia: equity and efficiency considerations

**Project team:** Dr Md Sayed Iftekhar<sup>1</sup> (leader; mdsayed.iftekh@uwa.edu.au), Dr James Fogarty<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; Department of Water; CRC for Water Sensitive Cities

Globally, billions of people depend on groundwater resources. Groundwater accounts for about 50 per cent of global drinking water and 43 per cent of global irrigation. In Australia, 5,000GL of water is sourced from groundwater per year, providing almost one-third of the total drinking water and 70 per cent of the water used in agriculture.

There are also many groundwater-dependent ecosystems of significant ecological value. However, in many parts of the world groundwater is being depleted at an alarming rate, causing substantial economic, environmental and ecological losses. Where groundwater extraction is licensed, regulators often respond to resource depletion by reducing all individual licences by a fixed proportion.

This approach can be effective in achieving a reduction in the volume of water extracted but it is not efficient. In water-resource management, the issue of the equity-efficiency

trade-off has been explored in a number of contexts, but not in the context of allocation from a groundwater system.

To mitigate this knowledge gap, an empirical case study for Western Australia's most important groundwater system – the Gnangara Groundwater System (GGS) – was conducted. Resource depletion is a serious issue for the GGS, and substantial reductions in groundwater extraction are required to stabilise the system.

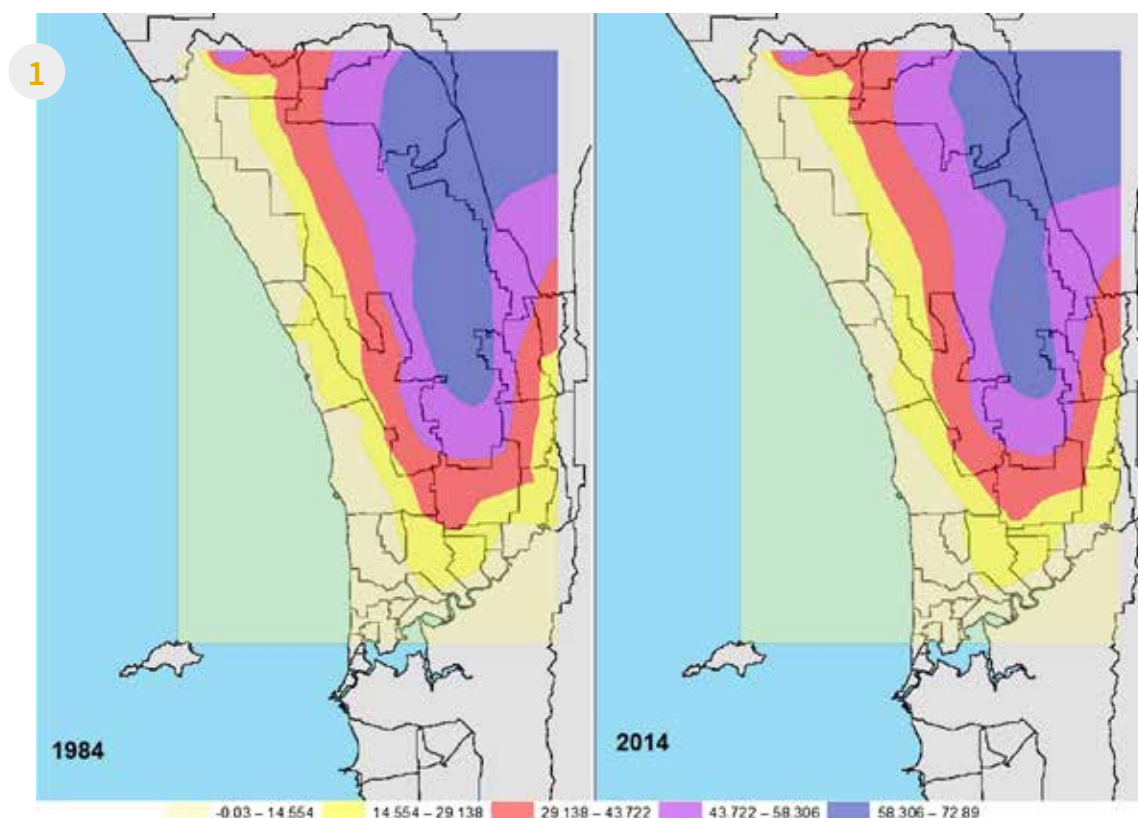
Using an individual-based farm-optimisation model, both the overall impact and the distributional impact of a fixed percentage water allocation cut to horticulture-sector licence holders is being studied. The model is parameterised using water licence-specific data on farm area and water allocation.

The modelling shows that much of the impact of water allocation reductions can be mitigated through changing the cropping mix and the irrigation technology used. The modelling also shows that the scope for gains through the aggregation of holdings into larger farms is much greater than the potential losses due to water-allocation reductions. The impact of water-allocation cuts is also shown to impact large farms more than small farms.

Adoption of a more efficient approach would allow stabilising groundwater resources at lower cost.

**This research is supported by the CRC for Water Sensitive Cities, and the WA State Government's Department of Water.**

**1 Caption:** Changes in minimum water level from 1984 to 2014.







## International Water Centre's Master of Integrated Water Management

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

The 2016 class of the Brisbane-based International Water Centre's Master of Integrated Water Management visited UWA for the Water and Agricultural Landscapes module.

The module is coordinated each year by IOA Adjunct Professors Jeff Camkin and Susana Neto and delivered through an intensive eight-day session based at UWA. The students learn through an innovative methodology that adapts the philosophy of co-learning to the needs of each participant, framed around their individual background, education and professional experience, and personal learning objectives.

The week included two full-day field trips. The first was to the Gnangara Mound, where students travelled with staff from the Department of Water to visit farms in Perth's peri-urban area. They explored the complex water- and land-management challenges of the Gnangara Mound, including climate change, population growth, increasing competition between agriculture, public and private water supply, and the maintenance of groundwater-dependent ecosystems.

The second field trip was to Cunderdin in the grainbelt, where Prof Ed-Barrett-Lennard and Prof Ken Flower guided the participants on a visit to the UWA/WA No-Tillage Farmers Association long-term no-tillage trial, to study the methods to improve soil organic carbon, water-use efficiency, crop yield and profitability in a low-rainfall environment.

On the final day, each participant gave a presentation on their learning journey throughout the week, highlighting how they intended to use what they learned in the module's final essay, the Master course and their future careers.

For more information on the International Water Centre's Master of Integrated Water Management, visit [watercentre.org/education/programs](http://watercentre.org/education/programs).

**2 Caption:** Prof Ken Flower discusses water-use efficiency in low-rainfall environments.

## Has selection for grain yield in wheat improved drought tolerance in the early vegetative phase?

**Project team:** Hackett Prof Kadambot Siddique<sup>1</sup> (leader; Kadambot.siddique@uwa.edu.au), Dr Yinglong Chen<sup>1</sup>, Adjunct Prof Jairo Palta<sup>1</sup>, Mr Faisal Younus Khan<sup>2</sup>, Mr Yupeng Feng<sup>3</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Higher Education Commission of Pakistan; <sup>3</sup>China Agricultural University, China

Improving crop yields in dryland environments is a high priority in global agriculture. Drought after crop emergence is a particular issue in the Mediterranean-type environment of southern Australia. In WA, early winter rainfall has been decreasing since 1900, exposing wheat crops sown at the onset of first autumn rains to increased risk of early-season drought during the vegetative phase. About eighty per cent of wheat growers in WA follow a dry-sown cropping program, which increases the risk of early-season drought. Wheat crops sown into dry soil will germinate on the first effective rainfall, potentially leaving crops vulnerable to 20-32 days of drought after emergence.

The overall aim of this project was to study the effect of early drought on growth and yield in wheat cultivars. Ten commercial wheat cultivars, released from 1958 to 2014, were used to (i) determine whether selection for grain yield in Australia has improved tolerance to early-season drought, and (ii) identify potential traits associated with variation in grain yield in wheat cultivars experiencing drought after emergence.

A glasshouse experiment was conducted from May to October 2016 in PVC columns (100 cm height and 15 cm diameter). There were two treatments at early stage (up to 32 days) i.e. well-watered and droughted. Plants were harvested (i) after 32 days of sowing, (ii) at anthesis, and (iii) at maturity. Soil moisture, leaf water potential, plant height, leaf area, number of tillers, root and shoot dry weight, photosynthesis, spike length, yield and yield components, and roots-related data was recorded to meet the objectives of research.

Wheat grain yield and biomass significantly decreased under drought stress at the seeding stage. The replacement of varieties significantly increased crop yield.

**This research was supported by the Higher Education Commission of Pakistan.**

**3 Caption:** Early droughted (L) and well-watered wheat plants at anthesis.





# Determining design criteria to maximise nutrient removal by vertical flow-through wetlands

**Project team:** Ms Rasha Al-Saedi (PhD Candidate; 21456205@student.uwa.edu.au), Adjunct Prof Keith Smettem, Hackett Prof Kadambot Siddique, Prof Andy Fourie

Constructed wetlands (CWs) are a natural alternative to traditional methods of wastewater treatment, and the focus of this study is on vertical flow constructed wetlands (VFCWs). VFCWs are highly regarded thanks to their outstanding cost savings, higher aeration capacity and minimal clogging issues. However, additional research is required into areas including efficient anaerobic degradation and denitrification rates, the difficulty in measuring denitrification rates in the field due to uncontrollable factors, and a lack of understanding the removal rates of key treatment parameters.

A laboratory-scale VFCW system was investigated as a batchwise to increase denitrification rates under steady-state conditions by improving substrate conditions for denitrifying bacteria. The presence of upflow saturated conditions, an external organic carbon source, an appropriate filter medium, and activated sludge contribution increases denitrification rates and therefore should be investigated further.

Temperature, redox, and pH revealed that all the conditions were mostly supportive for promoting denitrification. Substrate (nitrate) concentrations and cell mass in the system were monitored and estimated as a function of time, and the data was analysed to obtain the kinetic and stoichiometric constants. In general, a more efficient and stable nitrate removal was achieved in sucrose and ethanol contributions than controlled columns. These findings highlighted the importance of those factors in accelerating the denitrification rates in VFCWs.

A second experiment has introduced the possibility of detecting anammox (anaerobic ammonium oxidation) in CWs under ambient temperatures as well as expanding knowledge about the diversity of the microbial communities within CWs. Traditional denitrification could produce nitrous oxide, a greenhouse gas, therefore attention has been given to finding an alternative solution to treat wetlands that does not emit greenhouse gases. Recently, a combination of partial nitrification with anammox has attracted attention due to its benefits in enhancing nitrogen removal from receiving wastewater bodies and reducing greenhouse gas emissions. However, the implementation of these routes to pilot-scale wastewater treatment plants has been hindered by inflexible metabolic conditions and the extremely slow growth rate of the functional bacteria. Research has also not focused on the potential of canon process for removing nitrogen in CWs using more realistic conditions such as ambient temperature and gravel as a natural filter bed.



One stage of partial nitrification and anammox processes has been carried out in triplicate in the lab under ambient temperatures. The downflow Batch feeding strategy has been adapted to maintain stable steady state conditions in the system. DNA analysis was conducted for the accumulated biofilm in the system to characterise the microbial community and assess their role in the process. To date, the results have showed significant signs of nitrogen removal under anoxic and anerobic conditions. The final results would enable energy-efficient wastewater treatment in an ambient environment.

A third experiment investigated the relationship between accumulated organic matters (AOM) within substrate and clogging. Clogging is one of the worst operational problems for subsurface flow constructed wetlands and the purification capability drops considerably when clogging occurs.

One of the most important consequences of the clogging in VFCWs is the creation of surface ponding. Consequently, the amount of oxygen that enters the bed will not be sufficient to meet the requirements of the aerobic process.

The relationship between accumulated organic matters (AOM) within the substrate and clogging are not well understood. Moreover, AOM within substrate pores consists mainly of biofilms and organic particles that have not been biodegraded. The influence of these on clogging will be researched further.

Almost all experimental work has now been finalised and three papers will be published shortly.

**This research was supported by the Iraqi Government's Higher Committee for Education Development Scholarship.**

**4 Caption:** Prof Keith Smettem with PhD Candidate Rasha Al-Saedi in the hydraulic laboratory at UWA.







# 4 Food Quality and Human Health

## Theme Leaders:

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**Dr Michael Considine**, [michael.considine@uwa.edu.au](mailto:michael.considine@uwa.edu.au)



Diet quality has a major impact on the development and progression, and prevention and treatment of chronic diseases and disorders. Consumption of healthy foods is the cornerstone of efforts to improve diet quality in populations. We know that a higher intake of plant foods is associated with lower risk of chronic diseases. 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 research will develop, enhance, evaluate, and validate foods and food ingredients for their potential to improve human health. Foods can be bred, grown or processed to achieve desired levels of particular components. This provides the opportunity to market these foods for their enhanced health properties.

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.

An important outcome of this theme is to train the next generation of scientists and industry champions, and provide guiding knowledge on policy development for the Australian academic and industry bodies.

Developing healthier foods and food ingredients is an exciting challenge for Australian agri-food industries and will make a positive contribution to both the Australian economy and human health.



## Bridging the knowledge gaps to breed high-value, flavonoid-rich apples

**Project team:** Dr Michael Considine<sup>1</sup> (leader; michael.considine@uwa.edu.au), Prof Jonathan Hodgson<sup>1</sup>, Prof Kevin Croft<sup>1</sup>, Dr Catherine Bondonno<sup>1</sup>, Ms Nicola Bondonno<sup>1</sup>, Prof Wallace Cowling<sup>1</sup>, Dr Matthew Nelson<sup>3</sup>, Prof Tim Mazzarol<sup>1</sup>, Dr Elena Mamouni Limnios<sup>1</sup>, Mr Steele Jacob<sup>2</sup>, Mr Kevin Lacey<sup>2</sup>, Ms Diana Fisher<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA; <sup>3</sup>Kew Gardens; <sup>4</sup>Pomewest

The Australian horticultural industry has recognised the opportunity to add market value to fresh fruits and vegetables through knowledge of health-promoting compounds (phytonutrients). Flavonoids are a key group of phytonutrients that are rich in apple skin. Our previous research identified acute benefits in a number of cardiovascular functions from consumption of a skin-enriched apple meal. Nevertheless, there are a number of knowledge gaps, which this project seeks to address, particularly: (i) can we selectively breed a more flavonoid-rich apple? (ii) is there a market for a flavonoid-rich apple, and would consumers attribute a premium value to it? Additional ongoing research led by Professors Jonathan Hodgson and Kevin Croft seeks to extend knowledge of the cardiovascular functions of eating apples.

In 2016 we made significant progress towards aim (i), although data analysis is still underway. Fruit and genetic material were taken from 91 selections from the Australian National Apple Breeding Program (DAFWA, Manjimup). This included 20 cultivars, with the remainder advanced selections from the breeding program, which had already passed strict criteria based on desirable consumer qualities, such as appearance and taste. Importantly, the pedigree relationships of these lines were known, and span five generations within the breeding program. The flavonoid composition was determined, demonstrating considerable range in the candidates for cardioprotective functions. By combining this data with the pedigree relationships, Professor Wallace Cowling was able to demonstrate a high degree of heritability for some of the flavonoids (data in progress). Genetic screening of each line has also been performed and the task at hand, led by Dr Matt Nelson and Professor Wallace Cowling, is to integrate these fingerprints to the flavonoid and pedigree

matrix, in order to pave the way for genetic markers to speed selection of elite lines of flavonoid-rich apples.

Progress towards aim (ii) was also made, led by Professor Tim Mazzarol and Dr Elena Limnios. They have conducted a survey of more than 600 consumers in order to identify their buying preferences and extract a potential value of a flavonoid-rich apple, in terms of either price per apple or increased consumption.

National changes to the health-claims legislation provided further reason to be excited about the healthy prospects for fresh horticultural foods. After 13 years of health-claims prohibition, the Food Standards Australia New Zealand (FSANZ) code now enables new high-level health claims, if substantiated (FSANZ Schedule 1.2.7). While all fresh fruits and vegetables were previously allowed to make a general statement of “reduces risk of coronary heart disease”, this change paves the way for more specific, high-level health claims. Nevertheless, the case for substantiated benefits must be made to FSANZ.

**This research is supported by Horticulture Innovation Australia, partnered by DAFWA, and APC Pomewest.**

**1 Caption:** Apple trees at the DAFWA Australian National Apple Breeding Program, Manjimup WA. © Western Australian Agriculture Authority (Department of Agriculture and Food, WA).

## Development of nutritionally enhanced apples

**Project team:** Prof Jonathan Hodgson<sup>1</sup> (leader; jonathan.hodgson@uwa.edu.au), Dr Michael Considine<sup>1</sup>, Prof Tim Mazzarol<sup>1</sup>, Dr Catherine Bondonno<sup>1</sup>, Prof Kevin Croft<sup>1</sup>, Dr Elena Mamouni Limnios<sup>1</sup>, Ms Nicola Bondonno<sup>1</sup>, Ms Diana Fisher<sup>2</sup>, Mr Fucheng Shang, Mr Kevin Lacey<sup>2</sup>, Mr Steele Jacob<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA; <sup>3</sup>Australian National Apple Breeding Program; <sup>4</sup>Pomewest; <sup>5</sup>Horticulture Innovation Australia

This program of research and development is aimed at transforming the value of Australian-bred apples. The goal is to gather the evidence to support the marketing 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. We previously showed significant health benefits of a flavonoid-rich apple, which grabbed industry attention. During 2016 progress has been made on three key aspects of this research program:

Firstly, screening of current and new apple varieties for flavonoid content, and investigations of effects of storage on flavonoid content. Approximately 25 apple selections have been screened previously, some of which have now been screened in each of the three seasons. This will provide data on seasonal variation.

During 2016, the screening program was expanded and approximately 100 selections from the Australian National Apple Breeding Program are now being screened, as well as several commercially available varieties. In addition, the flavonoid content of apples before and after long-term storage has been measured to establish the stability of flavonoids during storage. This knowledge will provide a platform to select apples, assist breeding, and promote new flavonoid-rich apple varieties. The first of two manuscripts describing the results of these activities is now complete and will be published in 2017. A second manuscript will be written during 2017.

Secondly, a human intervention study has been completed to investigate if consumption of high-flavonoid apples can result in acute and sustained benefits on measures of vascular health. The study included 30 participants. The first of two manuscripts describing the results of this study is now complete and will be published in 2017. A second manuscript will be written during 2017.

Thirdly, studies have been performed to explore the market for flavonoid-rich apples. The aim of these studies was to examine consumer attitudes towards a new flavonoid-rich apple, which will be available to the public within three years. It explored attributes that motivate purchase of apples. Results of these studies will be available in 2017.

Another important component of this research program is evidence that the regular consumption of apples does provide benefits to human health. During 2016 two papers were published using data from a population of older women. The data showed that higher apple intake among these women was associated with lower risk of total mortality, and reduced abdominal aortic calcification, a marker of disease of blood vessels linked with heart disease.

**This research is supported by the Australian National Apple Breeding Program, DAFWA, Horticulture Innovation Australia and Pomewest.**

**2 Caption:** Cripps Pink apples at the DAFWA Australian National Apple Breeding Program, Manjimup WA. © Western Australian Agriculture Authority (Department of Agriculture and Food, WA).

## The genomic basis of clonal variation in Cabernet Sauvignon wine grapes

**Project team:** Dr Michael Considine<sup>1</sup> (leader; michael.considine@uwa.edu.au), Prof Ryan Lister<sup>1</sup>, Dr Patricia Agudelo-Romero<sup>1</sup>, Mr Wisam Salo<sup>1</sup>, Prof James Whelan<sup>3</sup>, Mr Glynn Ward<sup>2</sup>, Mr Richard Fennessy<sup>2</sup>, Mr Jim Campbell-Clause<sup>4</sup>, Mr James Freckleton<sup>5</sup>, Dr Paul Chambers<sup>6</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>DAFWA; <sup>3</sup>LaTrobe University; <sup>4</sup>WA Vine Improvement Association; <sup>5</sup>Yalumba; <sup>6</sup>Australian Wine Research Institute; AHA Viticulture; Cape Mentelle; Cullen Wines; Devil's Lair; Howard Park Wines; Moss Wood; Voyager Estate; Woodlands; Xanadu

Grapevine is the most economically important and most ancient fruit crop. More broadly, woody trees account for more than 95 per cent of fruit and nut production worldwide, by volume and value. Woody crops are propagated by cuttings, which enables the desirable qualities of the variety to be perpetuated.

However, somatic mutations arise spontaneously and accumulate through successive generations of propagation, resulting in phenotypic and agronomic differences, and the creation of new clones and ultimately new cultivars or trademarked clones.

Several important examples are the various sports of Pinot Noir, including Pinot Meunier, Pinot Gris and Pinot Blanc, all of which arose through somatic mutation of Pinot Noir, but which are now classed as varieties in their own right. In fact these examples highlight one of the major challenges in understanding the genomic basis of clonal variation, as the mutations exist only in the outer cell layer (L1); that is, the sports are chimeric, a mixture of two spatially separate genomes.

This project seeks to define the genomic basis of clonal variation in Cabernet Sauvignon, arguably the hero of the WA wine industry, and the third most valuable variety in Australia.

The challenges in this project are manifold. Firstly, there are several modes of genetic mutation, as well as other influences on the genome that do not, in fact, result in mutation of the DNA. Two principal modes of genetic mutation are discrete mutations, such as single nucleotide polymorphism (SNP) and insertion/deletion events, and transposition events, which can be grander in scale.

Each of these may pervade the entire somatic line or be restricted to particular cell types, as described above for the Pinot sports. These genetic variants are largely resolvable through application of next-generation sequencing of the DNA.

However, two additional modes are more cryptic. These are: epigenetic mutations, which are essentially chemical modifications of the DNA, but which are important determinants of gene expression; and viral infection, which can also alter gene expression. Neither of these modes require a mutation of the



3

DNA sequence per se, but nevertheless can result in considerable effects on phenotype, including yield and quality.

The additional challenge to resolving these modes is the vast complexity of the grapevine genome, which is confounded by a reference genome that is comparatively simple; that is, it was generated from a highly inbred clone, which in fact bears little resemblance to commercial varieties.

This project aims to investigate these modes, focusing primarily on DNA mutations in several of Australia's most commercially important clones of Cabernet Sauvignon. A team led by Dr Agudelo-Romero has determined the DNA sequence of 16 individuals, which includes some biological replication. More than 30,000 SNPs among this sample set have been identified, but the existing challenge is resolving which of these are true SNPs and not false-positives, as well as access to sufficient computational power to investigate more large-scale transposition events.

Access to the Pawsey Supercomputer, a vast computing facility funded by collaboration between the universities and federal government, will enable far algorithms that are not feasible on smaller-scale servers. The recent publication of the genome of a commercial Cabernet Sauvignon variety has provided this study with a valuable reference genome against which to determine the genetic variants of our clones.

The influence of virus in the table-grape variety Crimson Seedless is being investigated by PhD student Wisam Salo. Earlier studies by the DAFWA created a series of clones differing only in viral infection, which provides an unrivalled experimental resource.

Application of the outcomes of the research include the

ability for whole vineyards to be fingerprinted, establishing or confirming the identity of clones, and QC validation in commercial propagation. In addition, this will provide a foundation for exploring the genetic basis of different fruit and wine qualities of the various clones; for example, whether there are mutations in particular genes coding for flavour or aroma compounds.

**This research is supported by the ARC, DAFWA and the WA Vine Improvement Association with in-kind support from Yalumba Nursery and the Australian Wine Research Institute.**

**3 Caption:** Dr Michael Considine speaking to vineyard manager David Botting about clone trials at Howard Park Wines, Mt Barker, WA.

## Improved food crop varieties in Timor-Leste

**Project team:** Prof William Erskine<sup>1</sup> (leader; [william.erskine@uwa.edu.au](mailto:william.erskine@uwa.edu.au)); Adjunct Prof Harry Nesbitt<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; ACIAR; DFAT; Timor-Leste Ministry of Agriculture and Fisheries

Food security in East Timor became a major issue following its independence in 2002. With poor farming practices and increasing concerns over food security, Timor-Leste was ranked fourth on the Global Hunger Index by 2015. During the hungry season, which spans three to four months per year, farmers and their families experience severe food shortages, poverty and chronic hunger, leading to malnutrition and stunted growth in children.



An affordable and sustainable solution was needed that had to recognise local customs, gender roles, traditions and rituals around agricultural processes, and that could be implemented in a timely fashion when the rains come.

The main goal of the Seeds of Life (SoL) program, run from UWA, was to reduce the hungry season, increase crop production with new varieties of staple food crops, and develop an appropriate seed system to spread them nation-wide.

The research has resulted in the release of improved varieties of maize, sweet potato, rice, cassava and peanuts which out-yield local varieties by up to 150 per cent. All released varieties were selected after being cultivated under farmer conditions over a number of years and passing through a rigid consumer evaluation system. Crucially a national seed system was established using 1,200 community-based seed groups to disseminate quality planting material throughout the country.

An end-of-project survey in mid-2016 revealed that half (48 per cent) of all rural households in Timor-Leste were adopting improved varieties from the project. Better crop production and developments in agricultural processes have had a profound impact on the health and nutrition of the population of East Timor. New yields of staple foods are more productive and provide families with the vitamins, proteins and nutrients essential to improving calorie intake and overall health. The hungry seasons are now shorter and the population healthier.

The success of the program is being measured in improvements not only to food security but also in the capacity of the Ministry of Agriculture (MAF) to continue to support the seed system in the future. Five MAF staff completed MSc studies at UWA in the last five years.

**This research is supported by the Australian Centre for International Agricultural Research (ACIAR) and Australian Department of Foreign Affairs and Trade (DFAT).**

**4 Caption:** Farmers observe improved Seeds of Life maize varieties at a field day.

## Introduction of short-duration pulses into rice-based cropping systems in western Bangladesh

**Project team:** Prof William Erskine<sup>1</sup> (leader; william.erskine@uwa.edu.au), Dr Imran Malik<sup>1</sup>, Dr Matiur Rahman<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>International Rice Research Institute (IRRI); Bangladesh Agriculture Research Institute (BARI); Bangladesh Government Department of Extension; International Centre for Agriculture Research in the Dry Areas (ICARDA)

Bangladesh, despite progress, needs to achieve food security for the rapidly growing population. Traditionally pulses have complemented rice, which dominates the national diet, but national pulse production within rice-based cropping is under pressure because of competition from more remunerative irrigated crops. Pulses have been marginalised to the shrinking rain-fed areas of low productivity – partly also because of their susceptibility to biotic stresses. Pulse imports to fuel rising demand have overtaken production.

The reduction in plant-protein production is a major concern of Government. Crop diversification through intensification represents a strategy of growth in the agriculture sector that will concurrently improve household livelihoods and diets. Pulses contribute to diversification through their addition of fixed nitrogen and their contributions to soil health and overall system productivity.

To reinvigorate national pulse production, a project funded by ACIAR aimed to fit short-duration pulses (lentil, mung bean and field pea) into new cropping niches in western Bangladesh to improve food and nutritional security. Additionally we aimed to build the capacity of national growers and researchers to produce pulses.

The project concluded in 2016 with the following results by crop:

**Lentil:** In on-farm demonstration of relay sowing of lentil during the 2015 to 2016 season, farmers gained 17 per cent higher yield from relay sown crop compared to sole cropping. In other demonstration fields, mean yield advantage of project-recommended cropping technology (BARI cultivar, fungicidal application to control *Stemphylium* blight and line sowing) over control plots (i.e. farmers' practice) was 21 per cent.

**Mung bean:** The yield of project-recommended cropping technology (line sowing, sowing irrigation, timely weeding and insecticidal application) gave 20 per cent yield advantage over neighbouring farmers' (control) plot yields.

**Pea:** On-farm trials of green pea harvest to introduce the cropping pattern of monsoon rice - sole pea - irrigated rice, was conducted. The inclusion of an extra crop, pea (cultivar BARI Motorshuti 3) as green pod vegetable, increased farm productivity 1.4-fold over the dominant cropping sequence (monsoon rice - fallow - irrigated rice), and farm net income four-fold.





An end-of-project survey revealed farmers had adopted project-recommended optimum cultivation technology and as a result the production of lentil and mung bean has increased by 42 per cent and 37 per cent, respectively, over the duration of the project in the nine target districts. The project districts cover 70 per cent of the lentil-growing area in Bangladesh. Spill-over effect of project activity was observed by increase of lentil production by only 10 per cent in adjacent districts. The increased interest in mung bean also created work opportunities (weeding, harvesting and post-harvest processing) for women during the lean period kharif 1 (pre-wet season March-June), in western Bangladesh.

The project also aimed to replace the fallow period between monsoon rice and irrigated rice with a crop of peas. On-farm trials and dissemination of project-recommended technology through demonstrations shows that farmers are very enthusiastic about the short-duration variety BARI Motorshuti 3 as it can be harvested for green pods within 60 days, allowing a succeeding crop of irrigated rice and effectively replacing a fallow period. Farmer interest is creating a demand for pea seed; one farmer, Mr. Mintoo, converted his green-pod demonstration field into an area for seed production as an entrepreneur, and sold part of his product (100kg seed) during the growing season.

**This research is supported by ACIAR.**

**5 Caption:** Seed of green pea cultivar drying before sale.

## Genomic research to improve the value of the narrow-leaved lupin (*Lupinus angustifolius* L.) grain

**Project team:** Ms Karen Frick<sup>1,2</sup> (PhD candidate; karen.frick@csiro.au), Dr Rhonda Foley<sup>2</sup>, Dr Lars Kamphuis<sup>2</sup>, Hackett Prof Kadambot Siddique<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>CSIRO Agriculture and Food; Murdoch University Separation Science and Metabolomics Laboratory

Narrow-leaved lupin (NLL) is a major grain legume crop in Australia that has recently gained recognition as a human health food. However because it is a recently domesticated crop, certain undesirable traits must be addressed in order to increase the value of the grain.

This research focuses on the accumulation of quinolizidine alkaloids (QAs) in the grain – toxic secondary metabolites which must remain below 0.02 per cent in order for the grain to be used for food and feed purposes. Mechanisms of QA biosynthesis and transport, and responses of these to environmental conditions are poorly understood, with grain levels often exceeding the threshold. This project uses a genomic approach to identify and characterise genes involved in the biosynthesis and transport of QAs. Previous work for this project has investigated patterns of QA gene expression in plant tissues of several lupin species, as well as in NLL leaf tissue under drought and increased ambient temperature conditions.



In 2016, the impact of aphid predation on QA biosynthesis has been investigated in NLL cultivars. Aphids are a major insect pest of NLL and while QAs are known to offer the plant protection against predators, the impact of aphid feeding on QA production is currently unknown. The expression of QA biosynthetic genes in leaf material of infested and uninfested plants was measured, and mature grain was collected in order to measure grain QA levels. The involvement of the jasmonate pathway in the regulation of QA genes was also investigated. Sweet and bitter NLL plants were treated with or without methyl jasmonate and QA gene expression was measured in leaf material.

This work serves to investigate how the production of QAs is regulated in lupin, and to identify which environmental factors may cause grain QA levels to exceed the industry threshold. This will assist lupin breeders and growers in producing a higher-value NLL crop.

**This research is supported by University Postgraduate Award, GRDC and CSIRO Agriculture and Food.**

**6 Caption:** Narrow-leaved lupin infested with green-peach aphid to investigate how grain alkaloid levels are affected by aphid predation.









# 5 Agribusiness Ecosystems

## Theme Leaders:

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Agribusiness encompasses all the various business activities from the supply of farm inputs, on-farm production, manufacturing and processing of farm produce, to distribution, wholesaling and retailing of produce to the final consumer. From a scholarly perspective, it entails the study of vertical and horizontal coordination of food chains as well as the study of decision-making process within the firms in the food chains. Therefore, agribusiness scholarship encompasses the inquiry of business and economics issues ranging from on-farm and off-farm operational efficiency, marketing and supply-chain management, provision of financial services, strategic management, cooperatives and entrepreneurship development to education, training and capacity building. An agribusiness ecosystem is a holistic view of the behaviour and management practices of agribusiness firms that transcends a single supply chain or industry. It is premised on the ground that the success of any agribusiness firm does not depend only on how efficiently and effectively it is managed but also on how it effectively co-opts the complementary capabilities, resources, and knowledge of the network of other firms and institutions. Therefore, the Agribusiness Ecosystem theme seeks to address issues related to the governance, productivity, profitability and sustainability of agribusiness firms and industries by providing innovative policy solutions through research, training and capacity building. This is to be achieved from mapping the structure, growth, performance and economic health of selected agribusiness ecosystems by drawing in a wide range of expertise from social sciences fields, including economics, business strategy and entrepreneurship, geography, public policy and administration, sociology, and political sciences. The breadth of expertise spans not only the Australian context, but also North America, China, India, Bangladesh, South East Asia, Africa, Europe and many other parts of the developed and developing world. Here we provide highlights of research and training activities delivered through the Agribusiness Ecosystem theme.

# National Mutual Economy Report

**Project team:** W/Prof Tim Mazzarol (leader; tim.mazzarol@uwa.edu.au), Dr Elena Mamouni Limnios, W/Prof Geoff Soutar

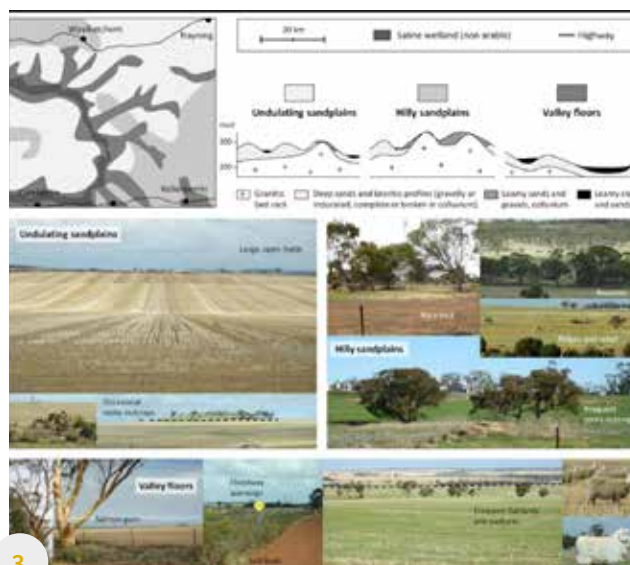
The UWA Co-operative Enterprise Research Unit (CERU) has been partnered with the Business Council of Co-operatives and Mutuals (BCCM) since 2012 in the development of an Australian Co-operative and Mutual Enterprise Business Index (ACME-BI) study. This is designed to track the size, structure, growth and decline of the sector via longitudinal analysis. A side product of this study is the generation of the National Mutual Economy Report, which was released for the first time in 2014. The 2016 National Mutual Economy report highlighted the size of the Australian co-operative and mutual enterprise (CME) sector as having about 2,000 enterprises with 29 million active memberships. The Top 100 CMEs had a combined annual turnover in FY2015 of \$30.5 billion, and combined assets of \$143.7 billion. Over the previous five years the Top 100 CMEs in Australia grew their annual turnover by an average of 18 per cent and their combined assets by 14 per cent. CMEs were found across most industry sectors, and the report showcased: the WA bulk grains handling and marketing co-operative CBH Group Ltd; the WA fishing co-operative, Geraldton Fishermen's Co-operative; the customer owned Bank Australia; the Victorian housing co-operative CEHL; the Hepburn Wind Park Co-operative (Vic); Pioneer Valley Water Co-operative, PVWater (Queensland); and shared services co-operative ArchiTeam (Vic).

## A new discipline to study farming diversity: introducing comparative agriculture to Australia

**Project team:** Ms Myrtille Lacoste<sup>1</sup> (leader; myrtille.lacoste@uwa.edu.au), Dr Ken Flower<sup>1</sup>, Prof Stephen Powles<sup>1</sup>, Dr Roger Lawes<sup>2</sup>, Dr Olivier Ducourtieux<sup>3</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>CSIRO; <sup>3</sup>AgroParisTech

New tools to study farming systems were trialled for the first time in Australia as part of a PhD project completed at the end of 2016. Comparative agriculture is an integrative discipline from France, and studies farming systems holistically through the acquisition of detailed farm information at regional scale. Outputs include farm profiles that are representative of the farming diversity of a given region. In this study, six profiles were identified for a 4000 km<sup>2</sup> area of the central grainbelt of Western Australia. These profiles differed in terms of land, labour, equipment and a range of practices, including farm-level strategies such as machinery renewal, grain storage, and the planning of crop-pasture rotations across the farm. Farm profiles can be used to determine drivers that explain differences in practices and performances. For instance:



cropping specialisation was associated with limited labour availability and light sandy land types dominating the farm; regional average farm values were shown to be inappropriate to represent real farms in the region; continuous cereal or pasture rotations are not common practice; boundaries in technical capacity were identified for each profile. Practical implications for local research, development and extension are numerous. Examples include improving the design of farmer surveys and field trials, the parameterisation of models, the allocation of research investments, and the contents of industry messages.

Using a novel type of literature-gap analysis, the project determined that no equivalent to comparative agriculture methods is currently being used in Australia.

Furthermore, the first ever comparison with mainstream multivariate statistical methods showed that comparative agriculture was more effective in determining farming profiles for the studied area. This is achieved using a mixed-method procedure that cost-effectively collects both qualitative and quantitative data. These tools could complement current methods to collect information from farmers.

This PhD project thus demonstrated the value of a discipline that deserves wider application. Using comparative agriculture to better understand how and why the practices, strategies and performances of farmers vary at the local scale could contribute to better address agricultural challenges.

**This project is supported by IPRS/APA award and the GRDC Grains Industry Research Scholarship.**

**3 Caption:** Landscape zones identified in the central grainbelt of WA where both land and practices differ. Photo: Myrtille Lacoste



## Governance structures and food safety standards in the shrimp value chain in Indonesia

**Project team:** Asst/Prof Amin Muger (leader; amin.mugera@uwa.edu.au), Dr James Fogarty, Ms Maharani Yulisti

Food safety has received significant attention in the fisheries global market due to health issues, free-trade agreements and increasing aquaculture production. Aquaculture is an important practice for developing countries such as Indonesia because it contributes to national food security, income source and foreign exchange earnings. Recently, aquaculture development in Indonesia has attracted the world's attention because Indonesia is the third largest producer in global aquaculture with major markets in the US, Japan and Europe. Importing countries protect their consumers by applying food-safety standards (FSS), which drives increased responsiveness and awareness among producers and governments in exporting countries.

The aim of this research project is to investigate the emerging governance structure of the shrimp industry in Indonesia and understand how this structure influences the implementation of food safety standards.

PhD candidate Maharani Yulisti completed fieldwork collecting data via in-depth interviews with key stakeholders in the shrimp value chain. A total of 34 interviews were conducted and transcribed from Bahasa into English. The data is currently being analysed. This project is supported by the Australian Award Scholarships.

**4 Caption:** Construction of a shrimp farm. Credit: Stephen Kennedy

## Nutrition insecurity and livelihood decision-making in rural Myanmar

**Project team:** Prof Bill Pritchard<sup>1</sup> (leader; bill.pritchard@sydney.edu.au); Prof Anu Rammohan<sup>2</sup>, Prof Michael Dibley<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>University of Sydney; <sup>2</sup>UWA; University of Community Health, Myanmar

The aim of this project is to generate new insights into the ways that nutrition outcomes relate to livelihood circumstances

in rural Myanmar. It does this in the context of considerable international research into recent years of persistent problems with chronic under-nutrition amongst agriculture-dependent households. International research has identified a disconnection between the contemporary trajectories of change in agricultural practices in the global south, and the nutrition security needs of agriculture-dependent populations. As Myanmar undergoes economic and political reform, insights into this question have key relevance to policies for agriculture, land and natural-resource planning, and food and nutrition.

The project addresses this research task through a systematic analysis of a unique dataset collected from a first-of-a-kind survey in six townships across three states/regions in rural Myanmar. This would:

- (i) address critical questions about food and nutrition insecurity in Myanmar by generating dietary and anthropometric data from our survey sample;
- (ii) assess this data against household indicators to propose an explanation of the socio-economic patterns of food and nutrition insecurity in rural Myanmar;
- (iii) use qualitative interviews to document household livelihood decisions and connect these findings to our survey data to generate a conceptual model of livelihood-nutrition pathways;
- (iv) interpret these findings with a view to informing global theory about the agriculture-nutrition disconnect and nutrition-sensitive development, and
- (v) disseminate findings in key national policy-making forums, at this vital moment in Myanmar's history.

The highlight of 2016 was the baseline survey of 3000 households, followed by a part of the qualitative research activity.

The three states/districts were selected to represent three major agro-climate zones:

- Magway is in the dry zone, with agriculture dominated by pulses, maize and, in areas adjacent to watercourses, rice. In Magway, the townships of Yesagyo and Pakokku are both sited on the western bank of the Ayeyarwady River. In each township, some villages have access to river-sourced irrigation, and some are dependent on dryland agriculture.
- In Chin (in the hilly zone), Mindat and Kanpetlet townships are in the extreme south, adjacent to Rakhine State. These townships were selected largely for travel and logistical reasons, given the highly isolated and difficult terrain of some of the other parts of Chin.
- Ayeyarwady, in the fertile Delta region, is the traditional rice bowl of the country, and also has important fishery resources. In Ayeyarwady, Kyaiklat and Maubin are both relatively close to Yangon, and hence may be expected to facilitate peri-urban and urban commuting livelihood opportunities, in addition to traditional agricultural pursuits.

The international collaboration has progressed well. A highlight has been the successful symposium held in Yangon in October. Additionally, a paper based on the first-draft results from the survey was presented at an international conference in Japan, and papers are being prepared for publication.





**This project is supported by an ARC Discovery Project Award.**

**5 Caption:** Prof Rahmoham interviewing rural female respondent in Maubin township (Ayeerwady)

## Can insurance mechanisms enhance the attractiveness of conservation auctions?

**Project team:** Mr Toto Olita<sup>1</sup> (PhD candidate; toto.olita@research.uwa.edu.au), Prof Steven Schilizzi<sup>1</sup>, Dr Md Sayed Iftekhar<sup>1</sup>, Prof Uwe Latacz-Lohmann<sup>2</sup>, Prof Peter Boxall<sup>3</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>Christian-Albrechts-Universitaet Kiel, Germany; <sup>3</sup>University of Alberta, Canada

Conservation auctions or tenders (CTs) are gaining popularity globally due to their ability to generate efficiency gains with limited public funding. CTs are used to allocate conservation management contracts to private landholders through a bidding process that is designed to attract bids of low cost and which provide great environmental benefits. The very nature of CTs facilitates competition among landholders, which pushes them to bid closer to their true costs. However, the existence of various types of uncertainties in delivering environmental goods can undermine the attractiveness of CTs as a conservation-policy instrument. Therefore, understanding the relationship between uncertainties and bidders' participation as well as bidding behaviour will help design more effective and efficient auctions.

Insurance mechanisms could be useful in mitigating some of the risks, as shown by their successful application in various fields. This study aims to provide insight on how to mitigate risks in conservation auctions by incorporating an insurance mechanism. The research team developed an optimal bidding model for a budget-constrained conservation tender and analytically explored the impact of an insurance mechanism on bidder's optimal bidding behaviour.

**This project is supported by an ARC Discovery Grant, Scholarship for International and Research Fees (SIRF) and UWA Top-up Scholarship.**



## Information exchange, learning and adoption of conservation agriculture in Malawi

**Project team:** Dr Atakelty Hailu<sup>1</sup> (leader, atakelty.hailu@uwa.edu.au), Mr Robertson Khataza<sup>1</sup>, Dr Marit Kragt<sup>1</sup>, Dr Graeme Doole<sup>2</sup>

**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>University of Waikato, New Zealand

Recent efforts to improve agricultural productivity in Africa have focused on the promotion of low-cost sustainable land-care strategies such as conservation agriculture (CA). Despite the widespread promotion of CA technologies, the adoption of these practices has remained low in Africa and elsewhere. The low rate of adoption is a result of a diverse range of factors; one of the notable causes being farmers' lack of information related to the performance of CA technologies. We hypothesise that delayed investment or under-investment in CA technologies could arise from insufficient information for two reasons: 1) even if farmers are aware about the existence of a new technology, they could still be uncertain about how best to use it from a technical perspective; 2) new technologies can be perceived as riskier than conventional ones given that uncertainty exists with respect to their performance across both space and time. Therefore, this study seeks to establish how information exchange and learning affect the timing of the adoption of conservation agriculture in Malawi. The study uses survey data collected from a randomly selected sample of 340 households, representing smallholder farmers who are engaged in sustainable agricultural intensification practices involving legume- and maize-based conservation agriculture. Using a discrete-time duration model (also known as event history or survival analysis), this study establishes that social learning through a network of peers, and access to extension advisors facilitate quick adoption of conservation agriculture technologies. Further, the results show that farmers who became aware of the existence of conservation agriculture during years of drought hazards were highly likely to adopt these practices. Overall, the results highlight the need for strengthening and targeting social networks as conduits for information about new technologies.

**This project is supported by Australian Award Scholarship.**

**6 Caption:** Low investment in R&D is a common cause of food insecurity in Malawi



## Assessing vulnerability to food insecurity in developing countries

**Project team:** Asst/Prof Amin Mugera (leader; amin.mugera@uwa.edu.au), Mr Mohammed Azeem, Prof Steven Schillizi, Mr Denis Abagna, Hackett Prof Kadambot Siddique

Extreme poverty remains a big challenge in many developing countries, including Pakistan, and is on top of the agenda for the Sustainable Development of the United Nations Development Group. There is a consensus among development practitioners and policymakers that ending poverty in all its forms needs to look beyond analysis of current poverty status and explore the likelihood of individuals who are not poor being pushed to become poor or those who are poor moving out of poverty in the near future; what is known as vulnerable to poverty.

The main goal of this research project was to provide a more holistic analysis and view of poverty and vulnerability to poverty in the Punjab province of Pakistan. The study sought to address four research questions:

- (i) Do the estimates of vulnerability to poverty using expenditure-based indicators and calorie-based indicators provide mutually consistent policy implications?
- (ii) What is the relative impact of household-specific and community-specific shocks on households?
- (iii) What is the role of social protection on helping individuals and communities cope with shocks?
- (iv) Do measures of poverty and vulnerability to poverty provide consistent policy implications?

To address those research questions, a large and high-quality data set was analysed: the Multiple Indicator Cluster Survey (MICS-2011) of the Punjab, generated by the United Nations Development Programme (UNDP), United Nations Children's Fund (UNICEF) and the Government of Punjab. The survey covered 150 towns/tehsils (administrative unit) of the Punjab with a sample size of 599,617 individuals in approximately 90,000 households. Another component of this research project investigated food poverty and vulnerability to food poverty and its determinants in Ghana, using the 2005-2006 Living Standards Survey. Analysis was based on the Foster-Greer-Thorbecke (FGT) and Vulnerability as Expected Poverty frameworks. Results indicate higher rates of vulnerability to poverty than prevailing poverty rates across different administrative regions. Urban households are found to be more vulnerable. Household size, dependency ratio and age of

household head are found to be vulnerability-increasing, while agricultural income, asset ownership, remittance and formal education are vulnerability-reducing. The results have policy implication in the design of poverty-alleviation programs.

**The project is supported by UWA Pakistan Flood Reconstruction Scholarship and the Australian Award Scholarship.**

**7 Caption:** The 2005-2006 Living Standards Survey was used to investigate food poverty and vulnerability to food poverty in Ghana. Credit: FMSC

## Evaluation of productive gains of adopting soil-conservation practices in central China

**Project team:** Zhihai Yang<sup>1</sup>, Asst/Prof Amin Mugera<sup>2</sup>, Ning Yin<sup>1</sup> and Yumeng Wang<sup>3</sup>

**Collaborating organisations:** <sup>1</sup>Huazhong Agricultural University, China; <sup>2</sup>UWA; <sup>3</sup>Renmin University of China, China

Soil degradation has been identified as one of the major challenges to the growth of agricultural productivity. This challenge is particularly daunting in rapidly developing countries with high population density and limited arable land to feed that population, such as China, India, Bangladesh and Pakistan. Soil conservation practices (SCPs) have been identified as key in maintaining and improving soil quality for sustainable agricultural production. Since 2006, the Chinese Ministry of Agriculture (MOA), with the support of the Ministry of Finance, has initiated a soil-improvement program in many major grain-producing regions, using organic manures, stubble retention and conservation tillage. However, it is not clear whether adoption of SCPs enhances technical efficiency in farms and hence agricultural productivity.

The aim of this research project was to evaluate and analyse the impact of adoption of soil conservation practices (SCPs) on the productive efficiency of smallholder rice producers in Central China. It also investigated the drivers of yield variability and inefficiency in production. The data used in this study is from a farm-level survey conducted in Hubei Province of Central China. A total of 312 adopters of SCPs and 338 conventional farms were surveyed and included in the analysis. We address self-selection bias and unobserved heterogeneity problems by estimating a switching regression model for the adoption-decision function and separate stochastic production frontiers for SCP and conventional farms while allowing for production inefficiency. We found that SCP farms exhibit statistically higher average technical efficiency than conventional farms. Education, extension services, membership in co-operatives, access to credit and alternative income sources are positively and significantly associated with technical efficiency for both groups. Conventional farms display higher partial output elasticity for land while only SCP farms show significant elasticity for capital.

**This research project is supported by China Scholarship Council.**



## Impact of food-based interventions on child nutrition outcomes in northern Ghana

**Project team:** Asst/Prof Amin Mugeru (leader; amin.mugeru@uwa.edu.au), Mr Abdul Kafayat, Dr James Fogarty

Malnutrition has been reported to be on the decrease in the past decades but it is still prevalent in Asia and sub-Saharan Africa. High levels of child malnutrition in developing countries largely contribute to child mortality and long-term effects on their cognitive development and productive capacity when they grow up. Ghana is one country in sub-Saharan Africa where child malnutrition is still a problem. A number of intervention programs have been initiated in Ghana to address the issue of child malnutrition; among those are food-based interventions initiated in the year 2004 by United Nations Children's Fund (UNICEF)-Ghana in collaboration with International Food Policy and Research Institute (IFPRI) and the University for Development Studies, with the aim of improving household micronutrient status. However, there is no evidence on which types of malnutrition interventions work well. Appropriate culture- and context-sensitive interventions and policies are required to improve maternal and child nutritional outcomes.

This research project investigated the impact of food-based interventions on under-five child nutritional outcomes and the determinants of under-five child nutritional outcomes in the northern region of Ghana. Analysis was based on an extensive household survey of 1,458 households collected in 2004. Seemingly unrelated regression (SUR) and propensity score matching (PSM) methods were used for analyses. Both methods provide consistent results indicating that linkages intervention as well as linkages with food-based intervention significantly reduced under-five child wasting.

The key determinants of under-five child malnutrition were found to be child's gender, incidence of diarrhoea two weeks prior to the survey, age and marital status of household head, and household size, as well as the health status of the primary caregiver of the child as measured by their body mass index. We also found that linkages intervention only has a negative impact on child stunting. We found that linkages as well as linkages in combination with food-based interventions worked well and were very significant in Northern Ghana to improve under-five child wasting. We observed that linkages

intervention reduces under-five child wasting by 21 to 23 per cent and linkages with food-based intervention reduces under-five child wasting by a range of 25 to 28 per cent.

**The project is supported by UWA and the Australia Awards Scholarship.**

**8 Caption:** Health and humanitarian aid worker provides food to children in Ghana. Credit\_FMSC

## Economic evaluation of Territorial Use Rights for Fisheries with common property problems

**Project team:** Ms Nguyen Thi Quynh Chi (PhD candidate; thi.q.nguyen@research.uwa.edu.au), Prof Steven Schilizzi, Assoc/Prof Atakelty Hailu and Dr Md Sayed Iftekhhar

Emerging as an innovation for improving the management of overexploited fisheries around the world, rights-based fisheries management systems are being implemented in the form of either species- or area-based management. This project focuses on area-based management systems known as Territorial Use Rights for Fisheries (TURFs), attempting to address two inter-related issues: economic impacts of TURFs; and fishers' preferences for monitoring schemes to ensure the enforcement of TURFs, within particular small-scale fisheries in Vietnam.

While there are numerous reviews on species-based management, there have been none on area-based management. To fill this gap, we undertook a critical review of the literature on Territorial Use Rights for Fisheries. A review paper titled 'Territorial Use Rights for Fisheries (TURFs): State of the art and the road ahead' was published in 2016. The paper reveals that there is a growing interest in investigating the real-world effects of TURFs, both positive and negative. The variability in TURF performance appears to be due to design features, enforcement behaviour of fishers, and specific contextual conditions, namely biological fishery characteristics, socio-economic aspects of fishers, and institutional arrangements. The bulk of the published research has focused on theoretical analysis and empirical evidence based on fishers' perception and experience. There has been little research on enforcement issues or how design features and management contexts influence performance.

This review emphasises the need for rigorous empirical analyses of TURF effects, including assessment of the cost-effectiveness of different enforcement schemes and the effects of contextual conditions on TURF performance. Addressing current shortcomings in the literature could improve the design, implementation and performance of TURFs worldwide.

**The project is supported by the Australia Awards Scholarship.**

**9 Caption:** Fishing village in Vietnam. Credit: JvL





## Household welfare, resource allocations and risk attitudes of smallholder coffee producers in Nepal

**Project team:** Mr Govinda Prasad Sharma (PhD candidate; govinda.sharma@research.uwa.edu.au), Dr Ram Pandit, Dr Benedict White, Dr Maksym Polyakov

Farming households in Nepal are characterised by the smallholding and subsistence mode of farming. Households face economic challenges, such as low income emerging from inefficient utilisation of the resources (particularly land and labour), and also experience farming risks and uncertainties that directly influence their wellbeing. They employ diversified farm and off-farm income strategies to meet their needs. Farm diversification such as cash-crop farming is used as a strategy by smallholders. Government strategically adopts some approaches targeting specific crops, groups and regions to improve farmers' livelihoods.

Organic coffee is prioritised by the Government of Nepal through National Coffee Policy 2004 as an export earning commodity to increase household income in the mid-hills region. The adoption of coffee, however, showed a mixed result, increasing in new areas while being abandoned in pioneering areas, where it was being replaced by alternative crops due to inherent risks. Further, the majority of households derived income from both farm and off-farm sources, primarily through labour allocations, including working abroad. Hence, a critical examination of household resource allocations was important for policies from a household-welfare perspective. The study focused on four components: firstly to examine the subsistence household's income diversification strategies; secondly to examine the welfare impact of farm and off-farm income on the household through income distribution and its inequality; thirdly to explore the economic dimension of coffee farming; and finally to measure risk attitude of farm households and examine the relationships between risk aversion, household income and resource allocations.

A household survey of 441 coffee producers from two representative districts – Gulmi and Lalitpur – was conducted to collect data to fulfil research objectives. A farm household model for allocation of labour, a Gini coefficient and regression-based inequality model for income inequality, a combined qualitative and quantitative approach for



livelihood strategies, and a CRRA (constant relative risk aversion) measure for risk attitude of coffee producers were all employed to answer the research questions related to the above objectives.

The result showed off-farm income as a major source of household welfare. Education appeared to be a key to enhanced household income, leading to increased access to off-farm sources including an access to domestic and international labour markets. The income distribution result showed that households in low (high) income quartiles had a higher farm (off-farm) income shares. Farm (off-farm) income decreased (increased) income inequality, which was the result of household's participation in high-return off-farm income portfolios. Coffee contributed marginally to household income. Households were risk-averse in general, showing greater risk aversion to income variation than price and yield fluctuations.

**This project is supported by the Federal Government of Australia's Department of Education.**

**10 Caption:** Farming households in Nepal are characterised by the smallholding and subsistence mode of farming.

## UWA's Behavioural Economics Lab (BEL)

**Project Team:** Prof Steven Schilizzi<sup>1</sup> (leader; steven.schilizzi@uwa.edu.au)

**Collaborating organisations:** <sup>1</sup>UWA, Central Queensland University, University of Alberta, Canada and University of Kiel, Germany

The BEL lab was set up in conjunction with CSIRO and the School of Psychology in late 2014 with the main goal of studying human behaviour in relation to natural resources and the environment. This includes use of resources like land, water and biological lifeforms, as well as environmental impacts such as waste management and greenhouse gas emissions. Just as importantly, studies explore strategies and policies to address the corresponding behavioural and decision-making challenges.

One such research program, funded by an ARC-Discovery grant, investigates the value of competitive tenders (CTs) for purchasing from private landholders, environmental services like revegetation, wildlife corridor establishment, or pesticide reduction. Australia is one of the countries that has pioneered this approach, with the Victorian BushTender and the WA ALR1 (Auction for Landscape Recovery) programs for example. Economic theory suggests CTs are a cost-effective way for society to obtain environmental services because they create competition between landholders for a limited number of conservation contracts, and bids reveal to some extent the costs of carrying out conservation works. CTs are a way to pay for unpriced environmental services as market prices are a way to pay farmers for agricultural goods. However, the assumption until now has been that bidders know the costs of carrying out the works, whereas this is rarely true in practice. This research asks whether CTs are of value if bidders have imperfect knowledge of their costs at the time of bidding, and also imperfect knowledge of the outcomes from their conservation efforts. In short, how does cost and outcome uncertainty affect the value of CTs as conservation policy tools?

This question is studied in large part by carefully designing lab experiments where students play the role of landholders and face exactly the same decision-making problem. The amount of uncertainty on their cost or their conservation outcomes is varied and the study observes how their decision to participate in the program and their bid levels respond. The problem is also studied in the field with real farmers to control for external validity of the results.

Initial findings have been surprising, and we are still working to interpret the data. Our initial belief that greater uncertainty should always have negative impacts has been proven wrong. The effects of uncertainty can be unexpected.

This is an international effort involving partners at CQU in Rockhampton (Qld), in Canada (University of Alberta) and in Germany (University of Kiel).

**This project was supported by an ARC-Discovery grant.**

## Agribusiness Training

### Capacity building in agribusiness productivity analysis in sub-Saharan Africa

**Project Team:** Asst/Prof Amin Mugera<sup>1</sup>, Dr Nyankoma Marwa<sup>2</sup>  
**Collaborating organisations:** <sup>1</sup>UWA; <sup>2</sup>University of Stellenbosch Business School, South Africa

Low levels of efficiency and productivity form one of the major causes of food insecurity, persistent poverty, and low standards of living for most countries in sub-Saharan Africa. Therefore, policy design to address those challenges requires information about productivity and efficiency shortfalls in smallholder and commercial agro enterprises and their main drivers.



Dr Amin Mugera from IOA visited the University of Stellenbosch Business School (USBS) in South Africa in August 2016 to deliver a five-day masterclass titled 'Applied Efficiency and Productivity Analysis for Agro-enterprises in Developing Countries'. Dr Nyankomo Marwa of the USBS coordinated the course. Twenty one participants drawn from ten countries in sub-Saharan Africa attended the class. The participants were people working in government departments, NGOs, the private sector and academia. The class was designed to familiarise participants with the fundamental principles and practice of performance benchmarking.

The course was a mix of theory and actual practice using hands-on-session computer exercises. Participants learned how to program different data envelopment analysis (DEA) models using Microsoft Excel and how to conduct empirical analysis using different packages of the open-source software R. They also learned how to benchmark performance using the statistical method stochastic frontier analysis (SFA).

Participants were able to appreciate the need for and role of performance benchmarking in informing policy debates on how to improve the efficiency and productivity of agro-enterprises. Those from non-agricultural related industries also noted that the skills and knowledge gained were equally important in their workplaces.

There was a general consensus among participants that this type of training was unique in the region and they would like to have more such training in the future. At the end of the course, most reported feeling empowered on how to conduct benchmarking studies.

**This project was supported by the Crawford Fund.**

**11 Caption:** Masterclass in South Africa

## Facilitating agribusiness development in Brunei Darussalam

**Project Team:** Asst/Prof Amin Mugera<sup>1</sup> (leader; amin.mugera@uwa.edu.au), Adj/Prof Peter Batt<sup>1</sup>, Adj/Prof Nazrul Islam<sup>1</sup>

**Collaborating organisations:** <sup>1</sup>UWA; Department of Agriculture and Agrifood, Brunei

To improve food security and facilitate exports of agricultural products from Brunei Darussalam, a three-day intensive



workshop was conducted with government and private enterprise to identify key institutional impediments and develop a holistic systems-based framework to support agribusiness development. The training program was designed based on the Agribusiness Ecosystems framework of the UWA Institute of Agriculture. The premise of this framework is that the challenges facing agribusiness are becoming more complex and require the involvement of multiple stakeholders from private, public and civil society actors. It advocates for a holistic systems-based approach to the agribusiness challenges where sustained competitive advantage can be gained through innovation and the ability of the sector to change and adapt to the market.

The training program was designed and delivered by Dr Amin Muger, Prof Peter Batt and Dr Nazrul Islam. A total of 51 participants from government (32) and the private sector (19) attended the three-day workshop. The topics covered were Agribusiness Ecosystem (Dr Amin Muger), Understanding Productivity (Dr Nazrul Islam), Agricultural Innovations and Adoption (Dr Amin Muger), Engaging with Customers (Prof Peter J Batt) and Value Addition (Prof Peter J Batt). Besides the interactive lectures, sufficient time was provided for participants to ask questions by engaging with the presenters and working in teams to brainstorm and map out challenges and opportunities for the Brunei agribusiness.

At the conclusion of the workshop, an official presentation of certificates to workshop participants was made in the presence of the Minister of Primary Resources and Tourism.

On the fourth day, the UWA team held a small workshop with key government and private sector decision-makers to identify the main challenges and opportunities for agribusiness development and how the team can be engaged in addressing those challenges.

The workshop was well received and covered by all major news outlets: The Brunei Times, The Borneo Bulletin, Media Permata and RTB, in both the English and Malay languages. The team also received excellent support from the Australian High Commission office in Brunei Darussalam. This project was supported by the Australian ASEAN Council.

**12 Caption:** Agribusiness workshop in Brunei





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# 6 Education and Outreach Activities

One of IOA's core strategies is to strengthen the communication links with industry, farmer groups and the broader regional and scientific communities. A number of communication channels are used to ensure the University's research in agriculture and related areas is adopted by its intended audience. Equally, for effective communication, IOA has a role in listening to growers, advisors and agribusiness professionals, to ensure their ideas and perspectives are considered in the identification of key issues and opportunities.

## 2016 International Year of Pulses

The United Nations Food and Agriculture Organisation (FAO) elected 2016 the International Year of Pulses to raise public awareness about the important contribution of pulses to sustainable cropping systems and to food and nutritional security, particularly in developing countries.

To support this mission, IOA Director Hackett Professor Kadambot Siddique was designated a Special Ambassador for Pulses and led UWA in participating in numerous events locally and internationally. Some of the highlights of the campaign included a presentation to approximately 50 key opinion leaders in the agriculture industry at the Royal Agricultural Society of Western Australia's annual show, with a pulse display in the Farm 2 Food Pavilion at the IGA Perth Royal Show.

The goal of the publicity was to increase awareness and understanding of the challenges faced by pulse farmers, traders and consumers so that influential people can in turn facilitate broad discussions around the nutritional and sustainable benefits of pulses.

IOA's International Year of Pulses campaign was wrapped up with a food drive to provide nutritious meals to struggling Australians. UWA staff, students and associates donated more than 150kg of pulses to Foodbank WA.

**1 Caption:** School children interacting with pulses at the IYP16 pulse display at the Perth Royal Show.



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## IOA Postgraduate Showcase: Frontiers in Agriculture

The IOA Postgraduate Showcase 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 tenth consecutive event, with seven students from the Schools of Animal Biology, Plant Biology, Earth and Environment, and Agricultural and Resource Economics presenting their research.

The Dean of UWA's Graduate Research School, Professor Kate Wright, gave the opening address, and the two sessions were chaired by Professor Harvey Millar, Director ARC Centre of Excellence in Plant Energy Biology, and Mr Tym Duncanson, WA Department of Water. WA's Chief Scientist gave the closing address and encouraged the students to continue communicating their research findings as often as possible. He said the onus was on scientists to promote research to the general public, government and funding bodies to ensure they continue to prioritise science.

The presentations can be viewed at [ioa.uwa.edu.au/publications/showcase](http://ioa.uwa.edu.au/publications/showcase).

<b>Mr Nathan Craig</b>	Seasonal factors influence the benefit of break crops under long-term no-tillage
<b>Mr Joseph Steer</b>	The blowfly's love of a sheep bum
<b>Ms Rebecca Owusu</b>	Feeding a hungry world: a paradigm shift for new innovations in agriculture
<b>Mr Dustin Severtson</b>	You can fly, but you can't hide: a tactical approach to managing cabbage aphids in canola crops
<b>Mr Abdulkareem Alsih</b>	Hydrology of dynamic water-repellent soils
<b>Mr Jacob Hawkins</b>	China's changing diet and its impact on greenhouse gas emissions: an index decomposition analysis
<b>Ms Anna Amir</b>	New forage plants: risks for fertilization and embryo development in sheep

**2 Caption:** 2016 cohort of students presenting in the Postgraduate Showcase: Frontiers in Agriculture





## Dowerin Field Days

The IOA team interacted with farmers, the agriculture industry, students and the rural community at the Dowerin Field Days in August 2016. The two-day event is one of the biggest agricultural shows in the country, hosting approximately 22,000 exhibitors and attendees.

The IOA display focused on the International Year of Pulses and was located in the Department of Agriculture and Food's (DAFWA) shed. PhD candidates Mary-Anne Lowe and Candy Taylor joined Emeritus Professor Lyn Abbott, IOA Communications Officer Diana Boykett, and Future Farm 2050 (FF2050) Project Officer Debra Mullan on the stand.

**3 Caption:** Pulses were featured at the Dowerin Field Days 2016 display.



## GRDC Grains Research Update, Perth

UWA was well represented by staff and students at the annual Grains Research and Development Council's (GRDC) Grains Research Update in Perth.

The event, facilitated by the Grains Industry Association of WA (GIWA), was held on 29 February and 1 March at the Perth Exhibition and Convention Centre, and attracted approximately 600 grains-industry personnel, growers and researchers.

**4 Caption:** Communications Officer Diana Boykett and Associate Professor Megan Ryan at GRDC Grains Research Update, Perth.



## Visitors to IOA

In 2016, IOA hosted more than 25 visitors from Pakistan, India, Mauritius, USA, China, Chile, Luxembourg, Germany, France and Australia.

These visits are crucial to strengthening research links and collaborations with institutions and industry both nationally and internationally.

The visitors included Endeavour Research Fellow Dr Ghulam Abbas who visited IOA from COMSATS Institute of Information Technology, Pakistan as a postdoctoral visiting scientist from March to August 2016. IOA also hosted Endeavour Fellow Dr Ruchi Bansal from the National Bureau of Plant Genetics Resources, India for six months from May to November 2016.

For further information, see [ioa.uwa.edu.au/publications/newsletters](http://ioa.uwa.edu.au/publications/newsletters)

**5 Caption:** IOA hosted more than 25 visitors in 2016.





## IOA Industry Forum

### ChAFTA's impact on agriculture in the spotlight

The China-Australia Free Trade Agreement (ChAFTA) and its impact on the agriculture industry was in the spotlight at IOA's 2016 Industry Forum, held at The University Club of WA on 7 July 2016.

Parliamentary secretary to the WA Minister for Agriculture and Food; Transport, Hon. Jim Chown, officially opened the forum, emphasising the importance of China as a trading partner to WA, to an audience of approximately 130.

This was followed by presentations from Grain Growers' trade and market access manager Cheryl Kalisch Gordon, CBH Group's Head of Trading Mr Trevor Lucas, and Ms Lili Pan and Mr Bryn Davies from MinterEllison who gave presentations on a range of perspectives based on their expertise. CSIRO's Dr Michael Robertson facilitated the panel discussion and provided a summary of the session.

After the event a reception was held, attended by approximately 80 people.

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](http://ioa.uwa.edu.au/publications/industry-forum)

**6 Caption:** Ms Lili Pan, Mr Bryn Davies, Mr Trevor Lucas and Dr Cheryl Kalisch Gordon discuss the impact of ChAFTA on Australia's agriculture sector.

## IOA News

IOA's broad range of activities is captured through its 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 May, August and December – *IOA News* is circulated widely in electronic format and hardcopy to approximately 6,000 readers.

## Online Presence

IOA's website, [ioa.uwa.edu.au](http://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.

The website was revamped in 2016 to reflect a more modern outlook.

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 2016, IOA solidified its social media presence on Twitter [@IOA\\_UWA](https://twitter.com/IOA_UWA). The number of followers doubled to 310 from the previous year.

## Media Statements

IOA continued communicating its research outcomes to the general public through the media by distributing 39 media statements in agriculture and related areas throughout 2016. A substantial amount of media coverage was generated in local, rural, national and international print, broadcast and online media.

Date	Title
12 January 2016	Research uncovers how to better manage crops grown on gravel soils
4 February 2016	Legume production vastly improves in International Year of Pulses
12 February 2016	Common antibiotic inspires hunt for new herbicide
4 March 2016	Mike Carroll's fellowship to benefit sheep production
1 April 2016	Addressing yield gap for global food security
13 April 2016	China's changing diet linked to higher emissions
19 April 2016	UWA Professor named FAO Special Ambassador for Pulses
26 April 2016	Swan Valley Honey Fest, the place to bee this Sunday
16 May 2016	International co-operation: shared problems, shared solutions
16 May 2016	Innovation across borders
16 May 2016	Strategic investment could leverage agricultural innovation and sustainability
16 May 2016	Fear and anxiety will compete with hope and success in zone's race for food
16 May 2016	New report urges connectivity and innovation for Indo-Pacific agriculture
16 May 2016	WA can do more to 'feed the zone'
23 May 2016	New seed 'flaming' technique to help with mine-site rehab
24 May 2016	Deregulation of Australian wheat export market not responsible for high price volatility
27 May 2016	Complex root tips could be the key to helping crops grow
30 May 2016	Intercropping maize and faba bean: the root of agro-diversity
2 June 2016	Researcher one step closer to developing non-allergenic 'super' peanuts
14 June 2016	UWA takes large steps to eradicate hunger in Timor-Leste
28 June 2016	Strong preference for local foods
29 June 2016	UWA Turf Water Allocation Project scores outstanding research award
11 July 2016	ChAFTA's positive impact on agriculture in the spotlight
3 August 2016	Growing legumes the solution to human health and sustainable food production
11 August 2016	Lack of copper in ancient soil regulates nitrification
18 August 2016	Carbon levels in soil affected by climatic conditions
1 September 2016	Decoding clover DNA leads to better livestock productivity
8 September 2016	All welcome to stargaze on UWA Farm
22 September 2016	Super-fast breeding system to double breeding efficiency in cereal crops
27 September 2016	UWA and DAFWA dig deep for soil science alliance
12 October 2016	Novel technique to study root system architecture brings breakthrough in crop production
24 October 2016	Farmers to improve grain yields by increasing organic matter in soil
2 November 2016	The UWA Institute of Agriculture releases Annual Research Report 2015
3 November 2016	Seed flamer wins at WA Innovator of the Year
9 November 2016	Breeding wheat for yield has improved water and nutrient-use efficiency
11 November 2016	Breakthrough in genetics advances Brassica crop improvement
28 November 2016	Bringing back genes from the wild for rapid crop improvement
20 December 2016	Food drive for Global Pulse Day
21 December 2016	Plants need oxygen for more than just survival

## Outreach and teaching activities at UWA Farm Ridgefield

In 2016, UWA Farm Ridgefield hosted more than 600 visitors. The visitors comprised students from UWA and other Australian universities, international university students and visiting academics (including from University of Liège, Shahrood University of Technology, Nagoya University and University of Zaragoza), and regional and urban community members with an interest in the Future Farm 2050 (FF2050) Project and UWA Agriculture.

The main outreach activity in 2016 was Pingelly Astrofest, held in September. UWA Farm Ridgefield and the International Centre for Radio Astronomy Research (ICRAR) hosted the popular event to showcase astronomy, Australian science, UWA and the FF2050 Project. The event attracted more than 300 people from regional and city-based areas, and was a fantastic way to bring communities together and help reduce the city-country divide – this is an important goal of the FF2050 Project, which recognises the community as a key player in the success of sustainable farming for the future. Trevor Keates, an astronomy expert based in Pingelly, presented on the history of astronomy in the shire, and Scitech provided a Spacedome and interactive science shows for all ages.

During 2016, approximately 170 UWA undergraduate students used Ridgefield for field work as part of the units Land Use and Management, Clean, Green and Ethical Animal Production, Avon Catchment, and Timber in Architecture. A third-year Science Communication student also undertook a six-week placement with the FF2050 Project during which she developed Social Media Strategy for the FF2050 Project and participated in event management at Ridgefield.

Approximately 45 postgraduate students and several Master of Science students also used UWA Farm Ridgefield for field work. Courses included Sustainable Grazing Systems, Advanced Land Use and Management. In addition, Ridgefield was used for research by ten PhD students from UWA (Ecosystem Restoration and Intervention Ecology/School of Plant Biology, School of Animal Biology, School of Earth and Environment) and Murdoch University (School of Veterinary and Life Sciences).

Student volunteers contributed to planting 4,370 native trees and shrubs at Ridgefield in 2016. The trees were planted in partnership with Greening Australia as part of the FF2050 Project and the federally-funded 20 Million Trees Project, to rehabilitate non-arable areas. A UWA undergraduate student in Natural Resource Management assisted with an audit of planted trees and found that, since 2012, survival of planted trees at Ridgefield has averaged 60 to 70 per cent.

UWA Farm Ridgefield also hosted 'Making sense of soils in the paddock', an e-demonstration of the weather station and monitoring tools as part of DAFWA's e-connected grainbelt. The field day was attended by members of the local farming community, Narrogin Agriculture College and UWA staff and students.

From September 2015 to March 2016, UWA Farm Ridgefield hosted four interns from high-level French agricultural



colleges (AgroParisTech, Montpellier SupAgro, Ecole Nationale Supérieure Agronomique de Toulouse and Agrocampus Ouest). These international students gained hands-on agricultural experience while contributing to the successful completion of harvest and other farm activities. Two additional exchange students from the University of Liège in Belgium and Shahrood University of Technology in Iran also used Ridgefield to complete their research.

In 2016 the FF2050 Project commenced the development of a Massive Open Online Course (MOOC) for Coursera, titled 'Discover Best-Practice Farming for a Sustainable 2050'. The course is a massive outreach project allowing individuals from all around the world to learn about the FF2050 Project and UWA Farm Ridgefield.

In June 2016, Australian Merino Sire Evaluation Association (AMSEA) held a committee meeting at Ridgefield as part of the management of the national Merino Lifetime Productivity Project that is being run on Ridgefield from 2015 until 2022, in partnership with Murdoch University.

In addition to outreach and teaching activities at UWA Farm Ridgefield, a number of external activities were conducted. In October and November 2016, Professor Graeme Martin and Emeritus Professor Lyn Abbott visited Kelmscott Senior High School Specialist Agriculture students to discuss the FF2050 Project and sustainable agriculture.

Professor Phil Vercoe presented to the National Association of Agricultural Educators at its Annual National Conference in Denmark in January ('The UWA Future Farm 2050 Project – Addressing the Future of Australian Agriculture'), while in August Professor Graeme Martin presented the FF2050 Project – including a tour of Ridgefield – to approximately 20 undergraduate students from North West Agricultural and Forestry University (China). Professor Graeme Martin also presented seminars on the project at Blayney, NSW, Charles Sturt University, the public lecture series 'Sex in 3 Cities' (Edinburgh, Nottingham and London), University of Bristol, the Global Farm Platform International Conference (University of Bristol) and the United Nations Association of Australia World Food Day.

In 2016 the FF2050 Project and UWA Farm Ridgefield were featured on the following podcasts: A real world sustainable and profitable farming program Part I, Part II: restoring biodiversity in sustainable farming, and Part III: Clean, green and ethical farming.

**7 Caption:** Ten telescopes on display at Pingelly Astrofest, held on UWA Farm Ridgefield in September 2016.



## Public Lectures and Special Seminars

In 2016, IOA hosted four public lectures:

Date	Presenter	Organisation	Title
31 March 2016	Dr Michel Meuret	National Institute for Agricultural Research, France	Pastoral livestock systems in France: managing productivity, landscapes and communities
14 June 2016	Prof William Erskine	UWA	Here's how Western Australian researchers have put a stop to hunger in Timor-Leste
9 November 2016	Dr Ejaz Qureshi	ACIAR	ACIAR's Agricultural Development Policy program and its research priorities: impact of policy projects
1 December 2016	Dr Michael Udvardi	Samuel Roberts Noble Foundation, USA	Nitrogen crises in agriculture and potential solutions

## Memoranda of Understanding

Institution	MOU Signed
Jawaharlal Nehru University, New Delhi, India	February 2016
Tottori University, Japan	June 2016
Dandaragan Camel Dairies Pty Ltd, WA	August 2016

## Awards and industry recognition for staff in 2016

Name	Award
Hackett Professor Kadambot Siddique	Fellow of the Indian Society for Plant Physiology
Hackett Professor Kadambot Siddique	United Nations Food and Agriculture Organisation Special Ambassador for Pulses 2016
Mr Benjamin Congdon	Best student Oral Presentation Award at the 13th International Plant Virus Epidemiology Symposium, Avignon, France
Dr Parwinder Kaur	AW Howard Research Fellowship Award
Prof Daniel Murphy and team	CRC for Polymers Chairman's Award for Excellence in Commercialisation
Dr Louise Barton	2016 Parks and Leisure Australia WA Research Award
Adjunct Assoc/Prof Muhammad Farooq	(COMSTECH) Outstanding Researcher Award, Ministerial Standing Committee on Scientific and Technological Cooperation of the Organisation of Islamic Cooperation
Adjunct Assoc/Prof Muhammad Farooq	Best Young Research Scholar Award from Higher Education Commission of Pakistan
Dr Andrew Guzzomi	2016 WA Innovator of the Year – Mitsubishi Corporation Emerging Innovation
Hackett Professor Kadambot Siddique	GIWA Award Recognition of services to Western Australia's pulse industry
Hackett Professor Kadambot Siddique	Visiting Professor, Institute of Soil and Water Conservation, Chinese Academy of Sciences
CRC Polymer team (Prof Daniel Murphy, Asst/Prof Matthias Leopold, Gavan McGrath, Jeremy Bougoure, Falko Mathes)	Vice-Chancellor's Impact and Innovation Award
Yongjuan Guan	Faculty of Science Publication Awards for Early Career Researchers 2016 – Feeding the World

## Research Projects and Research Training

### New Research Projects 2016

Title	Funding Period	Funding body	Supervisors
Effects of poultry litter biochar on cucumber production & soil microbial activity in a fertigation system on sandy soils	2016	Energy Farmers	Dr Zakaria Solaiman
Characterising structural variation in the canola genome	2016–2018	ARC Linkage	Prof David Edwards, Prof Jacqueline Batley

Title	Funding Period	Funding body	Supervisors
Soil microbial processes associated with retention of soil carbon after application of composted manure to dairy pastures	2016–2017	South West Catchments Council (NHT)	E/Prof Lynette Abbott, Dr Sasha Jenkins, Mr Ian Waite, Dr Zakaria Solaiman
Unravelling the drivers of greenhouse gas emissions in estuaries	2015–2017	Southern Cross University ex ARC Linkage Projects	Professor Bradley Eyre, Dr Matthew Hipsey, Dr Badin Gibbes, Dr Dirk Erler, Dr Damien Maher, Dr James Udy
Prediction in complex aquatic environments: response models for key south-west estuaries	2016	WA Department of Water	Dr Matthew Hipsey
Water quality changes in Vasse-Wonnerup estuary system in response to surge barrier	2016	WA Department of Water	Dr Matthew Hipsey
Northern Australian Environmental Resource Hub – Project Plan 2	2016–2019	Charles Darwin University ex National Environmental Science Program (NESP)	Prof Michael Douglas, Dr Matthew Hipsey, A/Prof Samantha Setterfield, Dr Sarah Prout Quicke, Prof David Pannell
CBH Research Program	2016	Co-operative Bulk Handling Ltd	Dr Elena Mamouni Limnios, Prof Timothy Mazzarol, Prof Kadambot Siddique, Prof Geoffrey Soutar
Impact of water-level manipulation in Great Lake	2016	Hydro Tasmania	Dr Matthew Hipsey
The more the merrier? Investigating copy number variation in Brassicas	2016–2018	ARC Discovery Projects	Prof Jacqueline Batley, Prof David Edwards
Facilitating agribusiness development in Brunei	2016	Australian ASEAN Council, DFAT	Prof Kadambot Siddique, Prof Tim Mazzarol, Dr Peter Batt, Dr Amin Mugeru, Dr Nazrul Islam
In touch with the environment: dissecting early tactile responses in plants	2016–2018	ARC Discover Projects	Dr Olivier Van Aken, Prof Harvey Millar, Prof Karam Singh
RnD4Profit – 14-1-022 – waste to revenue: novel fertilisers and feeds	2015–2017	Australian Pork Limited	Dr Sasha Jenkins, E/Prof Lynette Abbott, Mr Ian Waite
Spatial temperature measurement and mapping tool to assist growers, advisors and extension specialists manage frost risk at a farm scale	2015–2017	CSIRO ex GRDC	Dr Kenneth Flower, Mr John Callow, Dr Bryan Boruff
Impact of compost carbon on lettuce growth and soil fertility	2015	C-Wise	Dr Zakaria Solaiman
A long-term study to increase water-use efficiency, grain yield and the profit of growers in the western region in a no-till system	2016–2018	GRDC	Dr Kenneth Flower
An integrated platform for rapid genetic gain in pulse crops	2016–2019	GRDC	Dr Janine Croser
Environmental Livelihood Security (ELS) for climate-smart landscapes: a preliminary investigation for informing agricultural policy in the South Pacific	2016	ACIAR	Dr Eloise Biggs, Dr Eleanor Bruce, Dr Bryan Boruff, Dr Nathan Wales

Title	Funding Period	Funding body	Supervisors
Economic analysis of policies affecting pulses in Pakistan	2016	ACIAR	Dr Elizabeth Petersen, Dr David Vanzetti, Dr Muhammad Qasim, Dr Abdul Ghafoor, Dr Khuram Sadozai
Improving yield by optimising energy use	2016–18	ANU ex International Wheat Yield Partnership	Prof Harvey Millar, Dr Nicolas Taylor
An integrated platform for rapid genetic gain in pulse crops	2016–18	GRDC	Dr Janine Croser, Dr Federico Ribalta, Prof William Erskine
Phosphorus-efficient pastures that deliver high nitrogen- and water-use efficiency with reduced costs of production across southern Australia	2016–19	Meat & Livestock Australia Rural R&D For Profit Program	Assoc/Prof Megan Ryan, Prof William Erskine, Prof Timothy Colmer
A pre-breeding and genetic diversity project in spring canola for NPZ Australia, based at The University of Western Australia 2016/17	2016–18	Norddeutsche Pflanzenzucht Hans-Georg Lembke Kg	Prof Wallace Cowling
Improving chickpea adaptation to environmental challenges in Australia and India	2016–17	SA Research & Development Institute SARDI ex Australia India Strategic Research Fund AISRF	Prof Timothy Colmer
Physical management options for herbicide-resistant weeds – targeted tillage	2016–17	University Of Sydney ex Grains Research & Development Corporation GRDC	Dr Andrew Guzzomi, Assoc/Prof Michael Walsh, Dr Michael Widderick, Dr Bhagirath Chauhan
Exploring the scope for new crop suitability at Marvel Loch, Western Australia	2016	Virtue Australia Foundation	Hackett Prof Kadambot Siddique, Dr Chris Johansen, Prof Timothy Colmer
New approaches to quantifying the properties of gravel soils and for sampling inverted soils to improve crop management	2016-18	WA Department Of Agriculture & Food DAFWA ex Royalties For Regions	W/Prof Mohammed Bennamoun
SoilsWest Alliance – Agriculture	2016-18	WA Department Of Agriculture & Food DAFWA ex Royalties For Regions	Dr Frances Hoyle, Prof Daniel Murphy

## New PhD research students

Four students commenced their postdoctoral studies in agriculture and related areas at UWA in 2016.

Name	Topic	School	Supervisor(s)	Funding Body
Mr Enoch Wong	Development and regulation of soil water repellence in cropping soils	School of Earth and Environment and IOA	Dr Louise Barton, Dr Matthias Leopold, Dr Phil Ward (CSIRO), Prof Daniel Murphy	CSIRO ex GRDC
Ms Victoria Francisca Figueroa Bustos	Heat stress in wheat	School of Plant Biology and IOA	Hackett Prof Kadambot Siddique, Adj/Prof Jairo Palta, Dr Yinglong Chen	CONICYT Scholarship, Chile
Ms Ly Le	Salinity tolerance	School of Plant Biology and IOA	Hackett Prof Kadambot Siddique	UWA IPRS
Mr Habib Rijzaani	Diversity in banana	School of Plant Biology and IOA	Prof Dave Edwards	



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## Theme Leaders

The Theme Leaders coordinate 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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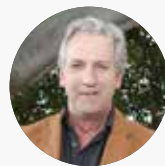


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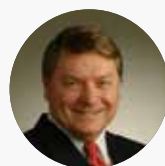


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## Institute Management Board (IMB)

The Institute is governed by its Institute Management Board, chaired by the Dean, Faculty of Science. The Board consists of Heads of School within UWA's Faculty of Science, the IOA Director and a representative from relevant Research Centres.



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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)**

Director of Livecorp; Director of Grain Producers Australia



**Dr Michael Robertson**

CSIRO, Deputy Chief, Ecosystem Sciences



**Mr Rod Birch**

Farmer



**Mr Shane Sander**

Founder of Agvise Management Consultants



**Mr Dawson Bradford**

Farmer, Chair of Lambex, and Chairman, WAMMCO



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Hackett Professor of Agriculture Chair and Director, IOA, UWA



**Mr Rob Dickie**

Government and Industry Relations, CBH Group



**Mr Ben Sudlow**

Manager, Fertiliser Sales and Marketing, CSBP



**Mr Tym Duncanson**

Operations Manager South, Water for Food, Department of Water



**Ms Tress Walmsley**

CEO, InterGrain



**Mr Philip Gardiner**

Farmer



**Mr Neil Young**

Farmer



**Prof Tony O'Donnell**

Dean, Faculty of Science, UWA



**Ms Bianca Tabbakh (Executive Officer)**

Business Manager, IOA, UWA

# 2016 Publication List

## Peer Reviewed Journals

- Ahmad A, Thomas GJ, Barker SJ and MacLeod WJ (2016). Genotype resistance, inoculum source and environment directly influence development of grey leaf spot (caused by *Stemphylium* spp.) and yield loss in narrow-leaved lupin (*Lupinus angustifolius*). *Crop and Pasture Science* **67**: 81-90
- Allan CJ, Jones B, Falkiner S, Nicholson C, Hyde S, Mauchline S, Ferrier DA, Ward P, Siddique KHM and Flower KC (2016). Light grazing of crop residues by sheep in a Mediterranean-type environment has little impact on following no-tillage crops. *European Journal of Agronomy* **77**: 70-80
- Akter S, Erskine W, Branco LV, Agostinho OF, Imron J and Spyckerelle L (2016). Gender in crop production in Timor-Leste. *ACIAR Proceedings* **146**: 158-164
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- Ashworth MB, Walsh MJ, Flower KC, Vila-Aiub MM and Powles SB (2016). Directional selection for flowering time leads to adaptive evolution in *Raphanus raphanistrum* (Wild radish). *Ecological Applications* **9**: 619-629
- Ashworth MB, Han H, Knell G and Powles SB (2016). Identification of triazine-resistant *Vulpia bromoides*. *Weed Technology*. **30**: 456-463
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- Ayalew H, Liu H and Yan GY (2016). Quantitative analysis of gene actions controlling root length under water stress in spring wheat (*Triticum aestivum* L.) genotypes. *Crop and Pasture Science* **6**(5): 189-494
- Ayalew H, Dessalegn T, Lui H and Yan G (2016). Performance of Ethiopian break wheat (*Triticum aestivum* L.) genotypes under contrasting water regimes: potential sources of variability for drought resistance breeding. *Australian Journal of Crop Science* **10** (3): 370-376
- Azeem MM, Muger A, Schilizzi S and Siddique KHM (2016). An assessment of vulnerability to poverty in Punjab, Pakistan: Subjective choices of poverty indicators. *Soc Indic Res* DOI 10.1007/s11205-016-1419-x
- Azeem MM, Muger A and Schilizzi S (2016). Living on the edge: Household vulnerability to food-insecurity in the Punjab, Pakistan. *Food Policy* **64**: 1-13
- Azeem MM Muger A and Schilizzi S (2017). Poverty and Vulnerability in the Punjab, Pakistan: A Multilevel Analysis. *Journal of Asian Economics* **44**:57-72.
- Aziz MM, Palta JA, Siddique KHM and Sadras VO (2016). Five decades of selection for yield reduced root length and increased nitrogen uptake per unit root length in Australian wheat varieties. *Plant Soil* DOI 10.1007/s11104-016-3059-y
- Bacon SA, Mau R, Neto FM, Williams RL and Turner NC (2016) Effect of climate warming on maize production in Timor-Leste: interaction with nitrogen supply. *Crop & Pasture Science* **67**:156-166
- Banik BK, Durmic Z, Erskine W, Revell CK, Vadhanabhuti J, McSweeney CS, Padmanabha J, Flematti GR, Algreiby AA and Vercoe PE (2016). Bioactive fractions from the pasture legume *Biserrula pelecinus* L. have an anti-methanogenic effect against key rumen methanogens. *Anaerobe* **39**: 173-182
- Barbetti MJ, Li CX, You MP, Singh D, Agnihotri A, Banga SK, Sandhu PS, Singh R and Banga SS (2016). Valuable new leaf of inflorescence resistances ensure improved management of white rust (*Albugo candida*) in mustard (*Brassica juncea*) crops. *Journal of Phytopathology* **164**: 404-411
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- Barker SJ, Si P, Hodgson L, Ferguston-Hunt M, Khentry Y, Krishnamurthy P, Averis S, Mebus K, O'Lone C, Dalugoda D, Koshkuson N, Faithfull T, Jackson J and Erskine S (2016). Regeneration selection improves transformation efficiency in marrow-leaf lupin. *Plant Cell Tiss Organ Cult* **125** (2): DOI 10.1007/s11240-016-0992-7

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- Batley J and Edwards D (2016). The application of genomics and bioinformatics to accelerate crop improvement in a changing climate. *Current Opinion in Plant Biology* **30**: 78-81
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- Borger CPD, Hashem A, Powles SB (2016). Manipulating crop row orientation and crop density to suppress *Lolium rigidum*. *Weed Research* **56**: 22-30
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- Busi R and Powles SB (2016) Transgenic glyphosate-resistant canola (*Brassica napus*) can persist outside agricultural fields in Australia. *Agriculture, Ecosystems and Environment*. **220**: 28-34
- Busi R and Powles SB (2016) Cross-resistance to prosulfocarb + S-metolachlor and pyroxasulfone selected by either herbicide in *Lolium rigidum*. *Pest Management Sci* DOI 10.1002/ps.4253
- Busi R, Girotto M, Powles SB (2016) Response to low-dose herbicide selection in self-pollinated *Avena fatua*. *Pest Management Science* **72**: 603-608.
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- Chen Y, Shan F, Nelson MN, Siddique KHM and Rengel Z (2016) Root trait diversity, molecular marker diversity, and trait-marker associations in a core collection of *Lupinus angustifolius*. *Journal of Experimental Botany*
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# Acronyms

<b>ACIAR</b>	Australian Centre for International Agricultural Research
<b>AMSEA</b>	Australian Merino Sire Evaluation Association
<b>ANU</b>	Australian National University
<b>AOM</b>	Accumulated Organic Matter
<b>APA</b>	Australian Postgraduate Award
<b>ARC</b>	Australian Research Council
<b>AWI</b>	Australian Wool Innovation
<b>BARI</b>	Bangladesh Government Department of Extension
<b>BLUP</b>	Best linear unbiased prediction
<b>CA</b>	Conservation Agriculture
<b>CAS</b>	Chinese Academy of Sciences
<b>CAAS</b>	Chinese Academy of Agricultural Sciences
<b>CBH</b>	Co-operative Bulk Handling (company)
<b>CCI</b>	Chlorophyll content index
<b>CERU</b>	Co-operative Enterprise Research Unit
<b>ChAFTA</b>	China-Australia Free Trade Agreement
<b>CIMMYT</b>	International Wheat and Maize Improvement Center
<b>CME</b>	Co-operative and Mutual Enterprise
<b>CSIRO</b>	Commonwealth Scientific & Industrial Research Organisation
<b>COGGO</b>	Council of Grain Growers Organisation
<b>CP</b>	Coat Protein
<b>CQU</b>	Central Queensland University
<b>CRC</b>	Cooperative Research Centre
<b>CRCNPB</b>	Cooperative Research Centre for National Plant Biosecurity
<b>CT</b>	Conservation Tenders
<b>CW</b>	Constructed Wetland
<b>DAFWA</b>	Department of Agriculture and Food, Western Australia
<b>DFAT</b>	Department of Foreign Affairs and Trade
<b>DNA</b>	Deoxyribonucleic Acid
<b>DPI</b>	Department of Primary Industries
<b>DSS</b>	Decision Support System
<b>DW</b>	Dry Weight
<b>EU</b>	European Union
<b>FGCS</b>	Fast generation cycling system
<b>FSANZ</b>	Food Standards Australia New Zealand
<b>GGs</b>	Gnangara Groundwater System
<b>GIWA</b>	Grains Industry Association of WA
<b>GRDC</b>	Grains Research and Development Corporation
<b>GnRH</b>	Gonadotrophin-releasing hormone
<b>ICARDA</b>	International Centre for Agricultural Research in the Dry Areas
<b>ICRAR</b>	International Centre For Radio Astronomy
<b>ICRISAT</b>	International Crops Research Institute for the Semi-Arid Tropics
<b>IOA</b>	The UWA Institute of Agriculture
<b>IPRS</b>	International Postgraduate Research Scholarships
<b>IWC</b>	International Water Centre
<b>IWYP</b>	International Wheat Yield Partnership
<b>MLA</b>	Meat and Livestock Australia
<b>MOOC</b>	Massive Open Online Course

<b>MOU</b>	Memorandum of Understanding
<b>mRNA</b>	Mitochondrial Ribonucleic Acid
<b>NILs</b>	Near isogenic lines
<b>NLMP</b>	National Livestock Methane Program
<b>NLL</b>	Narrow-leafed Lupin
<b>NPZ</b>	Norddeutsche Pflanzenzucht
<b>NSW</b>	New South Wales
<b>NSW-DPI</b>	New South Wales Department of Primary Industries
<b>OCS</b>	Optimal Contribution Selection
<b>P</b>	Phosphorus
<b>PAE</b>	Phosphate Acquisition Efficiency
<b>PCN</b>	Potato Cyst Nematode
<b>PHS</b>	Pre-harvest Sprouting
<b>PSbMV</b>	Pea seed-borne mosaic virus
<b>PUtE</b>	Phosphate Utilisation efficiency
<b>QTL</b>	Quantitative trait locus
<b>QA</b>	Quinolizidine alkaloids
<b>RELRP</b>	Reducing Emissions from Livestock Research Program
<b>RILs</b>	Recombinant inbred lines
<b>RIRDC</b>	Rural Industries Research and Development Corporation
<b>RNA</b>	Ribonucleic Acid
<b>RPP</b>	Ruminant Pangenome Project
<b>SA</b>	South Australia
<b>SARDI</b>	South Australian Research and Development Institute
<b>SCP</b>	Soil Conservation Practices
<b>SIRF</b>	Scholarship for International and Research Fees
<b>SOMER</b>	Spatially Orientated Model of the Evolution of Resistance
<b>SNP</b>	Single nucleotide polymorphism
<b>SMS</b>	Short Message Service
<b>TuMV</b>	Turnip Mosaic Virus
<b>TURF</b>	Territorial Use Rights for Fisheries
<b>UNDP</b>	United Nations Development Program
<b>UNE</b>	University of New England
<b>UNFAO</b>	United Nations Food and Agricultural Organization
<b>UNICEF</b>	United Nations Children's Fund
<b>UWA</b>	The University of Western Australia
<b>VFCW</b>	Vertical Flow Constructed Wetlands
<b>WA</b>	Western Australia
<b>WANTFA</b>	Western Australian No-Tillage Farmers Association



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