THE UNIVERSITY OF WESTERN AUSTRALIA

The UWA Institute of Agriculture

Annual Research Report 2015

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.

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The UWA Institute of Agriculture Annual Research Report 2015

Executive Summary

In 2015, The UWA Institute of Agriculture (IOA) successfully completed nine years since the institute was re-established in 2007. I am pleased to say that IOA's Strategic Plan 2015-2019 to capitalise on existing strengths and provide focus for new initiatives, was finalised and approved by IOA's Industry Advisory Board and the University's Executive.

IOA will continue to facilitate and co-ordinate to best advantage the research and development undertaken by the University's academic resource in 2015-2019. This may involve extending existing research areas, or the fostering of new research interests, either with existing staff, or through identifying key staff appointments to develop new areas of research and development.

In 2015 in the Shanghai Jiao Tong University's highly esteemed Academic Ranking of World Universities (shanghairanking.com), UWA maintained its position of 1st in Australia for life and agricultural sciences, and 25th in the world. Overall, UWA was ranked 87th in the world. In the National Taiwan University Ranking (http://nturanking.lis.ntu.edu.tw), which is based on performance ranking of scientific papers for world universities, UWA climbed four places to 30th worldwide for agriculture, and moved up six places to 18th worldwide for plant and animal science. This is a significant achievement made possible by committed partners, dedicated staff, challenging opportunities and strong support from the funding bodies and industry.

For the period 2015-2019, recognising industry opportunities and the existing staff strengths of the University, IOA supports members to further develop research themes in the following areas: Crops, Roots and Rhizosphere, Sustainable Grazing Systems, Water for Food Production, Food Quality and Human Health, and Agribusiness Ecosystems.

IOA's achievements during 2015 have been collated within five new research themes.

"IOA will continue to facilitate and co-ordinate to best advantage the research and development undertaken by the University's academic resource in 2015-2019."

Crops, Roots and Rhizosphere: Manipulation of root architecture and function, including rhizosphere biology, provides the next frontiers in advancing crop production by both genetic and agronomic means. It is an area where UWA has significant strength.

The theme has three major research, development and extension components: drought, transient waterlogging and mineral nutrition, with modeling, postgraduate training and technology exchange components being a part of each of the three areas. There is a large focus on root processes and the interaction of roots and soil abiotic and biotic environments, to enhance crop performance.

Sustainable Grazing Systems: Sustainable grazing systems are essential to provide feed for the various animal production systems in Australia and globally. These falls into two main types: extensive rangeland systems and mixed crop-pasture systems. IOA has been actively researching the crop-pasture and animal production nexus based on its own active research capability and in close cooperation with other national and international Research, Development, Extension and Adoption partners. This theme focuses on the contribution of livestock industries to the solution to global food supply.

Water for Food Production: Meeting the food needs of an increasing world population will require improved efficiencies in irrigated agriculture and better use of finite water resources. The challenge is to produce more food with less water. The development of irrigation schemes requires water 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.

This theme is underpinned by teaching and research components including economics, plant water use, agronomy and irrigation design. Industry collaboration and engagement, water balance, and irrigation modelling are a major focus.

Food Quality and Human Health: Development of healthier foods and food ingredients can make a positive contribution to both the Australian economy and human health. The development and validation of healthy foods that meet consumer desires is an exciting challenge for the Australian agri-food industries. To satisfy this growing need, we must train the next generation of scientists and industry champions and provide guiding knowledge on policy development for the Australian academic and industry bodies.

This theme focuses on the development of a collection of healthy functional foods and ingredients, and improved processes for their production and manufacture. The research delivers scientifically validated evidence for the promotion of new foods, and significant added value to agricultural industries.

Agribusiness Ecosystems: This theme focuses on addressing issues related to the governance of agribusiness firms along the food value chain with a focus on changing consumer behaviour due to changes in dietary and consumption patterns, adoption of new innovations, production and financial risk management, farm productivity and profitability, global food security and nutrition, commodity marketing, new venture creation and governance structure of co-operative enterprises.

It also examines the behaviour of agribusiness ecosystems and seeks to map the structure, growth, performance and health of selected agribusiness ecosystems drawing on multi-disciplinary expertise. The aim is to build a robust model of the agribusiness ecosystem that can be applied to regional, national and global contexts and used to develop in-depth understanding of how to facilitate these systems.

Education and Outreach Activities: IOA is committed to research training and facilitating the adoption of new technologies and practices. Ten PhD students commenced their research training, supervised by scientists from UWA and partner organisations and undertaking research in agriculture and related areas, in 2015.

Throughout the year, IOA distributed 31 media statements, organised several public lectures and annual engagement activities such as the Postgraduate Showcase and Industry Forum which were well-received. IOA also entered the realm of social media in 2015, with a Twitter presence (@IOA_UWA) to engage with the agriculture industry and wider community.

UWA Farm Ridgefield formed a major part of IOA's education and outreach activities, hosting numerous school groups and students. One of the highlights was the Field Day in September 2015 when the farm opened its doors to the wider community, to discuss managing risk in the capacity of climate, mental health and sustainability.

In summary, IOA has made excellent progress during the reporting period and I 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 throughout 2015.

Hackett Professor Kadambot Siddique AM, CitWA, FTSE, FAIA, FNAAS, FISPP
Hackett Professor of Agriculture
Chair and Director
The UWA Institute of Agriculture
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Crops, Roots and Rhizosphere

Theme Leaders:

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Manipulation of root architecture and function, including rhizosphere biology, provides the next frontiers in advancing crop production by both genetic and agronomic means.

Root and rhizosphere research is a new frontier compared to our knowledge of the above-ground plant components. Over the past decade, there has been increased interest in the interaction of roots with their soil biotic and abiotic environment. Furthermore advancements in techniques (microanalysis, molecular, omics) that unravel the mechanisms of microbial-plant interactions will aid with rhizosphere engineering.

Efforts are now being made to develop techniques (including molecular) for screening germplasm for variation in root traits and to exploit this variation by breeding for production benefits. The sequencing of the genome of the subterranean clover at UWA has created a unique resource for these activities (see Sustainable Grazing Systems theme). There is now a significant opportunity to harness this developing knowledge toward solutions for major issues in pasture and grain production imposed by soil constraints.

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 will be developed to 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.

Abiotic stress related research

Physiological basis of drought resistance in chickpea

Project team: Hackett Prof Kadambot Siddique[1] (leader; kadambot.siddique@uwa.edu.au), Dr Jiayin Pang[1], Prof Timothy Colmer[1], Prof Neil Turner[1], Prof Tanveer Khan[1], Mr John Quealy[1], Dr Yanlei Du[2], Ms Junlan Xiong[2]

Collaborating Organisations: [1]UWA; [2]Lanzhou University; The University of Adelaide; The University of Queensland; The University of Melbourne; South Australian Research and Development Institute (SARDI); RMIT University; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India

Terminal drought is a major constraint during the reproductive phase of chickpea growth. The aims of the project were to assess the chickpea germplasms in the dryland fields and understand the physiological mechanisms underlying drought tolerance in chickpea during the reproductive phase by undertaking detailed glasshouse experiments using large containers (106 kg of soil).

Some genotypes had consistently higher yield under water stress in the three dryland sites. In the glasshouse, some had consistently lower yield, whereas the seed yield ranking of some genotypes differed between glasshouse and the field (significant genotype × environment interaction).

The glasshouse study found that terminal drought imposed from early podding stage significantly reduced vegetative growth, reproductive growth, seed yield and water use efficiency for grain production in all chickpea genotypes.

Cultivar Neelam showed the highest seed yield among ten genotypes in the water-stressed (WS) treatment. Although the ten genotypes used the similar amount of water following WS, the pattern of water use in Neelam was different from the others. In Neelam, the slower water use at the early stage of reproductive phase would maintain higher transpirable fraction of soil water (FTSW) for a longer period during the reproductive phase, contributing to the higher yield. The young pods developed from flowers tagged when the FTSW was 0.50 had viable embryos, and had higher concentrations of abscisic acid than WW plants, but all pods ultimately aborted.

Pods, 16 days after flowering (DAF), which were developed from flowers tagged when soil water content reduced to 50% of field capacity in the water-stressed treatment (WS), while the soil water content was maintained at 80% of field capacity in the well-watered treatment (WW).

The FTSW at which the production of filled pods and seeds stopped coincided with that at which leaf stomatal conductance and leaf transpiration rate also first decreased, suggesting that either carbon shortage as a result of stomatal closure and/or ABA synthesis induced pod abortion and seed growth.

Identification of the genotypes with consistently higher yield at the dryland field sites and in the glasshouse with water stress provides confidence in these genotypes for possible use in breeding programs with the aim to improve yield of chickpea in water-limited environments.

This project is funded by Australian Government through Australia-India Strategic Research Fund (AISRF) Grand Challenge.

Phenotyping for salinity tolerance in chickpea (*Cicer arietinum* L.): from glasshouse to field

Project team: Prof Timothy Colmer[1] (leader; timothy.colmer@uwa.edu.au), Hackett Prof Kadambot Siddique[1], Prof Neil Turner[1], Assoc/Prof Katia Stefanova[1], Mr John Quealy[1]

Collaborating Organisations: [1]UWA; [2]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India; [3]Panjab University, India

Studies conducted over several years at ICRISAT and funded by the Council of Grain Growers Organisations (COGGO) identified a wide range of salinity tolerance among chickpea genotypes. A number of these genotypes have been introduced into Australia and were evaluated for salt tolerance in the glasshouse and field in 2012-2014.

The aim was to determine whether chickpea could be phenotyped for field

Chickpea plant in the glasshouse.

Is cluster-root formation in lupin species that avoid calcareous soils suppressed at high pH, high calcium levels or buffering capacity of high bicarbonate levels (or a combination thereof)?

Project team: Prof Hans Lambers[1] (leader; hans.lambers@uwa.edu.au), Mr Wenli Ding[1], Dr Peta Clode, Dr Jon Clements

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

In order to study the mechanism behind the calcifuge habit of some *Lupinus* species, especially under low phosphorus conditions, *Lupinus*

salt tolerance in the glasshouse. In the glasshouse the yields ranged three-fold in the saline soil, while in the field the yields varied from 60 to 150 g/m^2 in a wet year to 10 to 80 g/m^2 in a dry year. Some genotypes were consistently salt tolerant in the field and glasshouse, while others were consistently sensitive to salinity in the field and glasshouse. The rate of initial emergence and final number of seedlings that emerged in saline soil in glasshouse appear to be important determinants of yield under saline conditions in the field, particularly if planting is followed by a dry spell thereby concentrating salt in the germination zone.

Germination and emergence under saline conditions in the glasshouse or laboratory may provide a simple screen for salinity tolerance for chickpea breeders.

This research is supported by the AISRF.

Leaves of *Lupinus cosentinii* grown with high (left) and low (right) calcium concentrations. Photo: Wenli Ding

Leaves of *Lupinus albus* cv grown with high (left) and low (right) calcium concentrations. Photo: Wenli Ding

Dr Yinglong Chen and visiting Professor Peng Zhao, Henan Agricultural University, China, collect rhizosphere exudation from individual root tips to assess root physiological response to phosphorus supplies in two narrow-leafed lupin genotypes with contrasting root architecture and P efficiency.

species that were likely to respond differently to calcium were assembled, and the sensitivity to calcium under a low phosphorus supply was assessed.

Seven *Lupinus* species (9 genotypes, *L. albus* cv, *L. albus* wild, *L. angustifolius* cv*, L. angustifolius* wild, *L. luteus* cv*, L. pilosus*, *L. cosentinii*, *L. atlanticus* and *L. hispanicus*) were grown hydroponically at two combinations of calcium (Ca) and phosphorus (P) supply (a:10 μM P, 10 μM Ca; b: 10 μM P, 6 mM Ca). Photosynthesis (A_{max}), total biomass (dry weight) and leaf nutrient concentrations (including P and Ca) were measured; leaf symptoms were recorded and shown.

Lupinus species responded differently to the two calcium levels, with *L. angustifolius* wild, *L. cosentinii* and *L. hispanicus* showing leaf toxicity symptoms, *L. cosentinii* showing decreased total biomass, *L. albus* wild, *L. angustifolius* wild, *L. cosentinii* and *L. luteus* cv showing decreased A_{max} and all the species (except *L. angustifolius* wild) showing a decreased leaf iron (Fe) or magnesium (Mg) concentration at a high Ca level.

Ca toxicity was demonstrated for *L. angustifolius* wild, *L. cosentinii* and *L. hispanicus*, while the other species (*L. albus* cv, *L. albus* wild, *L. angustifolius* cv, *L. luteus* cv, *L. pilosus* and *L. atlanticus*) were tolerant of high calcium concentrations.

A high Ca concentration in the nutrient solution was associated with Fe or Mg deficiency in leaves.

The results that we obtained are quite different from most of the research results before (for example, *L. luteus* cv and *L. angustifolius* cv is intolerant of calcareous soils, while *L. cosentinii* is tolerant of calcareous soils), which shows that besides Ca, there are also other factors involved in the calcifuge habit of *Lupinus* species. Obviously, further research is needed.

This research is supported by the Australian Research Council (ARC).

Modelling spatial and temporal dynamics of rhizosphere exudation

Project team: Prof Zed Rengel[1] (leader, zed.rengel@uwa.edu.au), Dr Yinglong Chen[1], Dr Art Diggle[2], Dr Vanessa Dunbabin[3]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]Tasmania University

The aims of this ARC-funded Discovery Project are to characterise structural and functional root traits associated with spatial and temporal dynamics of exudation of various compounds into the rhizosphere soil to increase efficiency of capturing phosphorus (P) by crops growing in heterogeneous soils, and enhance simulation modelling capability at various scales (from a root segment to a whole plant) by improving the model of the 3-D structure and function of root systems via incorporating the knowledge of compounds and processes governing root exudation and crop capacity to

This study provides a fine research for the insight of root architecture and physiological responses to soil P. The variation in carboxylate exudation between the two genotypes and among P treatments may explain genotypic variability in P-acquisition efficiency. The benefits of having organic acid anions in the rhizosphere are twofold: they compete with phosphate groups for binding sites in the soil, and they form stronger complexes than phosphate with Al, Fe and Ca. Thus, they may help release phosphate from inorganic phases by ligand exchange or ligand-enhanced dissolution.

This research is supported by the ARC Discovery Project.

Phenotyping root traits in chickpea (*Cicer arietinum* L.) core collection

Project team: Hackett Prof Kadambot Siddique[1] (leader; kadambot.siddique@uwa.edu.au); Dr Michel Ghanem[2], Dr Yinglong Chen[1]

Collaborating organisations: [1]UWA; [2]International Centre for Agricultural Research in the Dry Areas (ICARDA)

Development of future chickpea (*Cicer arietinum*) cultivars with enhanced drought resistance and increased water-use efficiency is essential for improving chickpea adaptation to dryland environments. Root architectural traits influences nutrient and water uptake efficiency. Root traits that overcome biotic and abiotic constraints are critical to maintaining root length, function, and water capture, and are first order targets in breeding programmers for dryland environments.

However wide-scale use of root-related genetic information in breeding is hampered by relatively small mapping populations and inaccurate phenotyping. Therefore, the aim of this study was to phenotype and characterise root-related traits in order to translate recent physiological and genetic advances in understanding the role of root systems in improving yield and productivity.

Dr Yinglong Chen shows UWA's senior executive world collection of chickpea grown in the novel semi-hydroponic phenotyping platform.

During 2015, a large phenotyping experiment involving 270 genotypes of world collection of chickpea was carried out using the novel semi-hydroponic platform. This study identified wide variation in root system architecture across chickpea germplasm tested.

Some 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, chickpea genotypes with vastly different root properties were characterised for further studies ultimately aimed at developing germplasms with root traits for improved adaptation to specific environments.

This study and follow-up investigations through field and glasshouse experiments using molecular markers and/or QTL mapping are expected to identify candidate genotypes with suitable root traits for potential breeding for efficient water and nutrient capture in stressful or poor soil environments.

This research is supported by the CGIAR Research Program on Grain Legumes through ICARDA.

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

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

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 utilizing an embryo-culture based fast generation system and marker assisted selection. Indicators of drought tolerance will be evaluated in the parents and their offspring. Near isogenic lines (NILs) targeting on each of the major QTL will be developed and the expression profiles of mRNA and protein of each NIL pair will be compared under stressed environment which will lead to the identification of genes associated with drought tolerance.

Soil Moisture deficit at Zadoks scale 60 resulted in fewer effective tillers in wheat cultivar Westonia. Left = treatment, right

The primary objective is to gain a better understanding of the contribution of the tested major QTLs to drought tolerance in bred wheat. In 2015, experiments of gene action of the selected parents has been completed, and data analysis is underway. Pyramiding populations and NILs using the selected SSR markers are also being developed (F3).

This project is funded by UWA and the Endeavour Postgraduate Scholarship.

Dr Yinglong Chen explains barley growth and root development using the novel phenotyping platform to visiting collaborator Dr Tobias Wojciechowski, Forschungszentrum Juelich, Germany.

Characterising root traits for efficient water and nutrient acquisition in barley

Project team: Dr Yinglong Chen (leader; yinglong.chen@uwa.edu.au), Prof Zed Rengel[1], Hackett Prof Kadambot Siddique[1], Prof Jonathan Lynch[2]

Collaborating organisations: [1]UWA; [2]Pennsylvania State University, USA (PSU)

The Research Collaboration Award project aimed to use the state-of-the-art phenotyping, imaging and modelling technologies developed at UWA and Pennsylvania State University (PSU) to explore function and mechanism of the phenotypic variability in a set of barley genotypes.

Barley (*Hordeum vulgare* L.) is an important cereal crop in Australia, second only in production to wheat. Over 1.5 million tonnes of barley produced annually in Western Australia. Approximately 85% of Australian barley is exported, contributing some 20% of the world's traded malting barley.

In Australia, root systems of barley are poorly adapted to soils that have low water-holding capacity and poor nutrient availability. Low water supply, low phosphorus and low nitrogen fertility are the main factors limiting barley production. Decreasing water availability due to drying and variable climate in Australia's grain-belt exacerbates the nutrient deficiency stresses.

Development of future barley cultivars with enhanced drought resistance and increased water and nutrient acquisition efficiency is essential for improving crop adaptation in barley breeding programs, and relies on a better understanding of root structure and function.

However, knowledge of phenotypic variability in barley root systems is lacking. It requires both detailed description of the phenotypic variability in root traits and a mechanistic description of how the different traits influence water and nutrient acquisition in low-fertility drying soils.

In 2015, a combination of high-throughput phenotyping, Laser Ablation Tomography (LAT) imaging, and modelling simulation technologies were used to identify phenotypic variability in root anatomical and architectural traits, and explore how this variability influences water and nutrient acquisition and eventually crop growth and production.

Major research activities included phenotyping selected barley cultivars for root traits, and identifying genotypic variability in root anatomical and architectural traits. Dr Yinglong Chen visited Professor Lynch and his root labs at PSU and field stations in both Pennsylvania and Arizona in July–August 2015.

This collaborative project generated important information on the phenotypic variability in barley root architecture and anatomy in relation to water and nutrient acquisition efficiency, employed phenotyping, imaging and modelling technologies in the study of complexity of root property, and strengthened our long-term collaboration involving researcher exchange, training and collaborative grant applications.

The project makes an important contribution towards understanding barley root traits for efficient water and nutrient acquisition in dry and low fertility soils, and increases UWA's reputation in dryland agriculture through collaboration with the world's leading academic institutions.

The follow-up research will use barley as the model cereal crop and characterise root traits in a panel of cultivars and in biparental mapping population association and linkage mapping to identify genetic markers linked with specific root traits in collaboration with DAFWA and Kansas State University under the new ARC grant (DP160104434).

This research is supported by the UWA Research Collaboration Award, and PSU.

Effects of sowing depth on seedling emergence, early growth and rooting patterns of two wheat sister lines with contrasting tillering ability

Project team: Ms Jacinta Foley[1] (Honours student; 21130359@student.uwa.edu.au), Hackett Prof Kadambot Siddique[1], Adjunct Prof Jairo Palta[1,2], Dr Yinglong Chen[1]

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

Timeliness in sowing wheat crops is critical to ensure opportunities for early rainfall capture are maximised. Wheat may be sown earlier into dry soil to avoid sowing delays, but this creates a harsh growing environment due to inconsistent early rainfall, allowing shallow soil layers to quickly dry out.

Alternatively, wheat may be sown deeper to give seedlings greater access to deep soil moisture. However, deep sowing results in delayed emergence with fewer emerging plants, reduced tillering, smaller leaf area, less plant biomass and lower yield.

Rhizoboxes in the UWA glasshouse containing free-and restricted- tillering wheats sown at various depths. Photo: Jacinta Foley.

This study aimed to determine whether the genotypic tillering ability of wheat influences the impacts of deep sowing on emergence, early growth and rooting patterns. Sister wheat lines contrasting in tillering were used: one sister line with the tin gene (restricted-tillering) and the other line without it (free-tillering). Each line was sown at three depths: 3 cm, 4.5 cm and 6 cm. Plants were grown in rhizo-boxes in a naturally lit glasshouse for six weeks.

The restricted-tillering line had 30 % less tillers than the free-tillering line. The genotypic tillering ability did not influence the impacts of deep sowing on wheat as the sister lines had similar emergence times and reductions in early growth parameters when sown at 6 cm depth. Deep sowing of wheat at 6 cm compared to 3 cm depth resulted in delayed emergence by two days, and reduction in leaf area (49%), leaf dry weight (48%), tiller number (56%), shoot dry weight (49%) and total plant biomass (47%). Rooting patterns were influenced by sowing depth and genotype × sowing depth interactions. Wheat sown at 4.5 and 6 cm depth had smaller root systems with smaller biomass and less root tip number than wheat sown at 3 cm depth. The restricted- and free-tillering lines had similar root systems, this included similar root biomass, root tip number, specific root length and root thickness.

This study demonstrated that deep sowing of wheat at 6 cm depth results in slow emergence and poor early growth, independent of genotypic tillering ability, this indicates that either line 7750PF or 7750N may be used when deep sowing. Sowing wheat seeds at 3 cm depth is optimal for free- and/or restricted-tillering wheats in order to achieve good emergence and early growth.

This research was supported by the GRDC, Sir Eric Smart Scholarship and the Hackett Alumni Honours Scholarship.

Phosphorus-efficient legume pasture systems (UWA module)

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

Collaborating organisations: [1]UWA; [2]CSIRO; [3]DAFWA; [4]NSW DPI

As phosphorus (P) reserves diminish and prices of P fertilisers rise, it will be become necessary to develop more P-efficient farming systems. This project focuses on southern Australia's major annual pasture legume, subterranean clover, and utilises the "core collection" developed in a previous UWA/DAFWA ARC linkage project. The 97 accessions in the core represent 78% of the total diversity in the ~ 10 000 available accessions.

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

This project is split among a number of institutions – primarily CSIRO Plant Industry in Canberra (project home), NSW Department of Primary Industries (Wagga Wagga) and UWA. At UWA in 2015, several experiments examining

Field trial site near Pinjarra in September 2015.

exudation of carboxylates (organic anions) into the rhizosphere in annual legumes were conducted and the team concentrated on writing papers.

Assistance was again supplied to the Southern Dirt Farmers Group to undertake related field experiments. UWA PhD student, Mr Robert Jeffery completed his experimental work which included investigating the effect of arbuscular mycorrhizal fungi on the critical external P requirement of subterranean clover, and the impact of growing subterranean clover in a sward on root traits related to P acquisition such as root dry weight, specific root length, root hair length, mycorrhizal colonisation and rhizosphere carboxylates.

This research was supported by MLA and AWI (to CSIRO Plant Industry, Canberra).

Dynamics of arbuscular mycorrhizal fungi in perennial and annual pastures

Project team: Mr Ahmed Rashid Sukkar Alsharmani[1] (PhD Candidate; ahmed.alsharmani@research.uwa.edu.au), E/Prof Lynette Abbott[1], Dr Zakaria Solaiman[1], Asst/Prof Matthias Leopold[1]

Collaborating organisations: [1]UWA; [2]Evergreen Farming; [3]Wheatbelt NRM

Soil characteristics can influence the establishment and distribution of pasture species. This in turn, can affect the abundance of mycorrhizal fungi in the roots of the pasture species. This project is investigating soil factors in during establishment of perennial grass pasture species, at the UWA Farm Ridgefield.

In 2015, the pasture site, which had previously been maintained as an annual pasture and included salt-affected areas, was sown with a mixture of annual and perennial pasture species in collaboration with Evergreen Farming and Wheatbelt NRM. Phalaris, Tall Wheat Grass and Veldt Grass were the perennial grasses included.

Saltbush and other trees planted in salt-affected areas of the pasture site in 2015.

During 2015, the distribution of perennial and annual pasture plants was assessed in relation to soil physical, chemical, and biological characteristics. Significant variability in soil characteristics with sampling depth and sampling time was recorded across the site during this establishment phase. Survival of the perennial grasses will be monitored in subsequent years in relation to soil conditions and the colonisation of their roots by arbuscular mycorrhizal fungi.

Glasshouse experiments were conducted to investigate the influence of nitrogen and phosphorus fertilisers on mycorrhiza formation in the annual pasture plants present in the pasture. In addition, the effect of fertilisers of different elemental solubility on mycorrhizal communities and nutrient uptake in both perennial and annual pasture species were assessed.

This research is supported by Evergreen Farming and Wheatbelt NRM.

Farming in a biodiversity hotspot – harnessing native plants to reduce deleterious off-site phosphorus flows

Project team: Prof Hans Lambers[1] (leader; hans.lambers@uwa.edu.au), Assoc/Prof Megan Ryan[1], Mr Dion Nicol[1], Dr Carlos Ocampo[1], Prof Ed Barrett-Lennard[1], Prof Mark Tibbett[2], Prof Philip Brookes[3], Mr Stewart Jones[4], Dr David Bicknell[5], Ms Jane Townsend[7]

Collaborating organisations: [1]UWA; [2]Cranfield, UK; [3]Rothamsted, UK; [4]National Measurement Institute; [5]DAFWA; [6]Alcoa Farmlands; [7]Harvey River Restoration Taskforce

Flow of P from farmland into waterways is contributing towards eutrophication of waterways and estuaries around the world. In Western Australia this is a serious problem in many areas, including the Peel Harvey. A reduction in flow of P into waterways is urgently required in this region.

This project investigated whether uptake of P by P-resistant perennial native plants can reduce flow of P into shallow groundwater and waterways in the Peel Harvey (a seasonally variable landscape which consists of a patchwork of pastures and highly biodiverse remnant native vegetation).

2015 was the final year for experimental work for the project. The main focus was to examine the nutrient limitation to pasture growth on a high P pasture, typical of the Peel Harvey region. To do this we identified a typical dairy-farm soil high in P and low in N, S and K and grew seven pasture legumes and one grass with five nutrient treatments (nil, +P, +N, +SK, +NSK, +PNSK).

Shoot dry weight and nutrient content was measured over the growing season. No species was responsive to P. Traditional pasture species for this region (*Trifolium* spp. and *Lolium rigidum*) responded strongly to most, or all, other nutrients. However, *Ornithopus* spp. (serradellas) were not responsive to any nutrients in spite of similar shoot dry mass to the other species.

Pastures in this region currently are not using P efficiently due to limitation by nitrogen, sulfur and potassium. Farmers should therefore carefully assess their need for P (likely to often be minimal), nitrogen, sulfur and potassium. *Ornithopus* spp. should be further investigated for suitability for the pastures in this region.

This research is supported by ARC linkage with Greening Australia, the Harvey River Restoration Taskforce, DAFWA, Alcoa Farmlands and the National Measurement Institute. Greening Australia provided cash originally granted by the Alcoa Foundation.

Improving disease resistance in crops

Understanding resistance phenotypes to Turnip mosaic virus in oilseed Brassicas: strain specificity, inheritance and mechanisms

Project team: Ms Eviness Nyalugwe[1] (PhD Candidate; eviness.nyalugwe@research.uwa.edu.au), Prof Roger Jones[1], Prof Martin Barbetti[1]

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

A plant that eliminates itself is a good thing. Photo: Eviness Nyalugwe

Turnip mosaic virus (TuMV) causes diseases that pose a serious threat to *Brassica* oilseed crops and causes major economic losses globally.

This project aimed to evaluate germplasm of *B. juncea* (Indian mustard), *B. carinata* (Ethiopian mustard), *B. napus* canola) and several other *Brassica* species to identify lines with useful TuMV resistance phenotypes, and characterise the TuMV resistance phenotypes found and explore the resistance mechanisms involved.

It also aimed to determine the types of inheritance involved in TuMV resistance phenotypes found in *B. juncea*, establish the biological/genetic diversity of Australian TuMV isolates and deliver advice to breeders on which TuMV resistances to employ.

In 2015, new knowledge was obtained about (i) TuMV resistance gene *TuRBJU* 01 in *B. juncea,* demonsrating its effectiveness against 7 of 10 TuMV isolates, and (ii) resistance mechanisms Systemic Hypersensitivity (SHR) in *B. juncea* and Programmed Cell Death (PCD) in *B. carinata.*

Plants of susceptible parent JM 06006, parent Oasis Cl which carries gene *TuRBJU 01*, and F3 progeny plants from a cross between them were inoculated with 10 TuMV isolates. JM 06006 and Oasis Cl developed a susceptible phenotype with all isolates (JM 06006) or a systemic hypersensitive phenotype with all isolates except NSW-3 (Oasis Cl). In F3 progeny plants inoculated with all isolates except 12.5, 12.1 and NSW-3, the segregation ratios for necrotic: non-necrotic phenotypes all fitted a 3:1 ratio. However, 12.5 and 12.1, test data fitted a 3:1 ratio only on 2/2 and 1/4 occasions, respectively. Thus, *TuRBJU 01* was effective against seven TuMV isolates, less effective against 12.1 and 12.5, and overcome by NSW-3. *TuRBJU 01* will be useful in breeding TuMV-resistant *B. juncea* cultivars.

SHR was studied by light microscopy and histochemical analysis in *B. juncea* plants. Ten TuMV isolates were inoculated to leaves of JM 06006, cv. Oasis C1, and F3 plants from the cross between them. When stem cross sections were examined for the plant defence responses, phloem necrosis, hydrogen peroxide accumulation and additional lignin deposition, sections from plants with SHR demonstrated all of these characteristics, but sections from plants with systemic mosaic did not. Stems developing SHR had significantly more occluded xylem vessels (*P<0.001*) compared to plants developing systemic mosaic. Thus, phloem necrosis, xylem occlusion, lignification and hydrogen peroxide accumulation were all associated with the SHR in plants carrying gene *TuRBJU 01.* Phloem necrosis was apparently acting as the primary cause of SHR and xylem occlusion as an important secondary cause.

PCD pathways caused by TuMV were studied by light microscopy and electrolyte leakage following sap inoculation of *B.carinata* TZ-SMN 44-6 plants. Leaf responses to inoculation with avirulent (TuMV-avir) and virulent (TuMV-vir) isolates were compared at 2, 20, 52 hours after inoculation. The phenotypes induced were localised resistance (TuMV-avir) and systemic susceptibility (TuMV-vir). Dead cell number, deformation, percentage area and percentage integrated intensity, and conductivity of electrolyte leakage data, were analysed to examine their possible roles. Both isolates triggered morphological changes consistent with apoptotic-like PCD and necrosis-like PCD that depended upon isolate virulence and stage of infection reached, respectively.

This research is supported by the UWA Scholarship by Research Fees Award.

PhD candidate Ben Congdon investigates *Pea seed-born mosaic virus* in field pea

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

Project team: Mr Benjamin Congdon[1] (PhD candidate; benjamin.congdon@research.uwa.edu.au), Prof Roger Jones[1], Dr Michael Renton[1], Dr Brenda Coutts[2]

Collaborating organisations: [1]UWA; [2]DAFWA; New South Wales Department of Primary Industries

The goal of this project is to develop a forecasting model for *Pea seed-borne mosaic virus* (PSbMV) epidemics in field pea crops. This model would be used to inform a Decision Support System (DSS) for growers and advisors to enable effective integrated disease management in a Mediterranean-type environment. To do this we need to achieve a greater understanding of the driving factors behind PSbMV epidemiology.

2015 was an extremely successful year for the project with a number of highlights including the completion of the sixth and final year of field pea data collection blocks in Esperance and Muresk, which is to be used for model calibration and validation. Numerous pea samples and PSbMV isolates were collected from the field to be presented in an upcoming paper. The contact transmissibility of PSbMV between infected and healthy field pea plants was also established. This method of transmission had not been considered previously and has significant implications on the rate of PSbMV spread. This work has been published in the journal Plant Disease.

This work was presented at the 2015 Australasian Plant Virology Workshop in Fremantle to many esteemed plant virologists and at the Australasian Plant Pathology Student Symposium, in which the presentation was awarded ‘Best Presentation’ at this meet.

Significant progress has been made with model development.

In 2016 the forecasting model will be completed and extended to growers through SMS delivery with Blackspot forecasts as well as access to recommendations on control measures and further information. Upon completion, focus groups will be organised in field pea growing areas to promote use of the DSS and explain its outputs.

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.

This research is supported by the ARC and DAFWA.

Detection and epidemiology of spring aphids and redlegged earth mites.

Project team: Dr Ken Flower[1] (leader; ken.flower@uwa.edu.au), Mr Dustin Severtson[2], Asst/Prof Christian Nansen[3]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]University of California, Davis

This research was part of a PhD, with the focus on improving detection and sampling for aphids in canola. During 2015, a binomial sequential sampling plan was developed using data from five intensively sampled canola crops over two growing seasons. Yet to be published, the study determined that stratification of paddocks was necessary to reduce variability associated with large areas and strong edge effects. The sequential sampling plan optimised the sampling accuracy and sample number required to reach a decision to spray insecticide or not.

Further impromptu research was done using UAV-acquired multi-spectral imagery in a replicated canola field trial. Various potassium fertiliser regimes were established, then a 6-band multi-spectral camera was mounted to an 8-rotor UAV and images acquired over the canola plots at three growth stages of canola: seedling, stem elongation and early flowering.

Canola plots deficient in canola were classified with up to 99.9% accuracy using discriminant analyses of image data. Importantly, it was found that potassium deficient canola plants contained significantly higher populations of green peach aphids following a natural infestation at early flowering.

The study supports findings that UAV-acquired multi-spectral imagery has potential to identify regions containing nutrient deficiency and likely increased performance (i.e. presence) of arthropod pests. Potassium deficient plants had increased green peach aphid numbers, increased concentrations of nitrogen in youngest mature leaves, decreased vegetation cover (LAI), decreased normalised difference vegetation indices (NDVI) and decreased canola seed yield (i.e. up to 47% yield lower).

It is anticipated that mapped field regions displaying significant reductions in LAI and NDVI may be targeted for on-ground inspection for nutrient deficiency and early detection of pests.

This project is funded by the GRDC.

Eight-rotor unmanned aerial vehicle acquiring multispectral images of canola canopy.

Cabbage aphid infestation on flowering canola branches.

Characterisation of a major quantitative trait locus on wheat chromosome 3B responsible for *Fusarium* crown rot resistance

Project team: Prof Guijun Yan[1] (leader; guijun.yan@uwa.edu.au), Prof Chunji Liu[2], Dr Jun Ma[1,2], Dr John Manners[2], Dr Daniel Mullan[3], Ms Tress Walmsley[3], Dr Frédéric Choulet[4], Dr Catherine Feuillet[4] and Prof Jinkao Guo[5]

Collaborating organisations: [1]UWA; [2]CSIRO; [3]InterGrain, [4]French National Institute for Agricultural Research, [5]Shijiazhuang Academy of Agriculture and Forestry Science

Fusarium crown rot (FCR), a cereal disease caused by *Fusarium* species, could lead to a significant yield loss in wheat. Development of molecular markers that were tightly linked with the genes involved in FCR resistance in wheat is essential for marker-assisted breeding and could greatly increase the efficiency and precision of the breeding of resistant varieties to FCR. In our previous research, a genotype 'CSCR6' showed highly resistant to FCR among the 2,200 genotypes tested for disease resistance. Through QTL mapping study, a novel and major QTL located on chromosome 3BL has been identified in CSCR6 and nine pair of near isogenic lines (NILs) has been developed for this QTL.

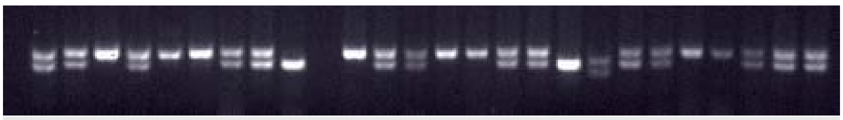
The project aims to derive a high resolution mapping population from the FCR NILs which will then be used to develop DNA markers that are tightly linked to FCR 3BL QTL. The genetic mechanism of FCR resistance in wheat will also be investigated using the FCR NILs.

In 2015, 45 plants that have recombination events inside the 3B CR QTL interval were identified by screening around 2400 offspring of several F15 heterozygous plants. These 45 plants were vernalised first and then grown in glasshouse during 2014-2015 for seed increasing and now the seeds are available. The performance of these homozygous recombinants to crown rot is being examined.

A mutant population containing around 1300 individuals from the resistant line of one near isogenic line pair (NIL 1A) was generated. The M2 plants are growing in glasshouse to a higher generation until further use. The genome sequence of 3B chromosome of NIL 1A is generated and the sequence data is being analysed.

Because of the close relationship observed between drought and FCR, 23 drought tolerance related traits in the same population used for previous FCR QTL mapping were measured to investigate the relationship between 3BL FCR QTL and drought tolerance QTL. Among the QTL identified, two QTL controlling malondialdehyde (MDA) content and leaf width are found to be located close to the 3BL FCR QTL. Particularly, the NILs developed for FCR 3BL QTL also segregated for MDA content, suggesting a possible association between the genes for drought tolerance and FCR resistance. Two papers were published based on these results.

This project is funded by the ARC.



Screening for homozygous candidates in the NIL-derived population using a self-developed gene-based marker W223. The lines with one band were the homozygous candidates.

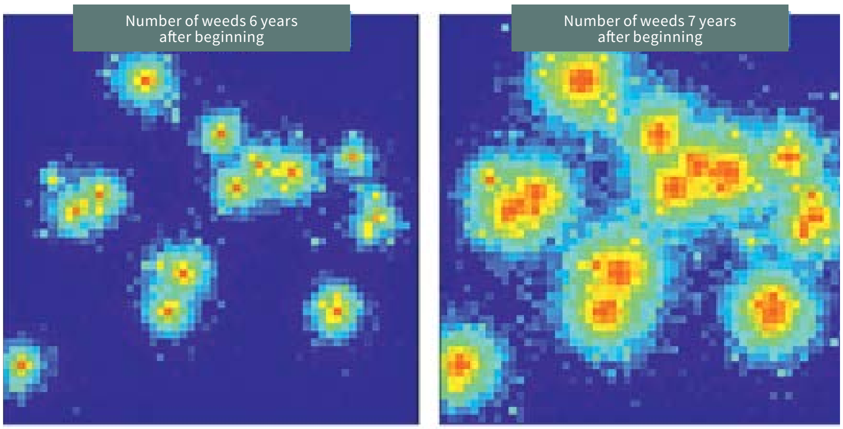
Spatially-explicit modelling of herbicide resistance evolution

Project team: Ms Gayle Somerville (PhD Candidate; gayle.somerville@research.uwa.edu.au), Dr Michael Renton, Prof Steven Powles, Dr Michael Walsh

Weeds are a major constraint to agricultural production throughout the world. Herbicides are the key method of controlling weeds in many agricultural systems, and thus the evolution of herbicide resistance poses a major threat to sustainable production.

Simulation modelling is an essential tool to help understand, predict and manage evolution of resistance. The vast majority of herbicide resistance modelling studies have not been spatially-explicit, and thus implicitly assumed that weed populations are spatially-homogenous with fully random mating. However, in reality weed populations are usually very spatially heterogeneous and structured in terms of density (ie patchy), genetics and mating. This project aims to investigate whether more realistic spatially-explicit modelling leads to different predictions, novel management recommendations, and new insights.

In 2015, Dr Michael Walsh joined the team of supervisors to provide expertise and input on harvest weed seed control. A first study using non-spatially-explicit modelling to investigate possible reasons to explain differing speeds of evolution of resistance for different types of herbicides, was finished and a paper describing this study written. A new spatially-explicit model of herbicide resistance evolution that incorporated pollen and seed spread was constructed and parametrised. A first study using this model showed that predicted rates and patterns of resistance evolution were quite different when spatial structure was



Results from spatially-explicit simulation of herbicide resistance evolution Photo: Gayle Somerville

accounted for explicitly. A paper on these results was presented at the MODSIM 2015 conference, Gold Coast, and a paper published in the proceedings. The model has since been further refined and new features such as spread through harvesting machinery and multiple resistance genes have been added. A new more detailed study of the effects of spatial resolution and different kinds of spread mechanisms has been conducted, and a new journal paper on these results is being written.

Ms Somerville and Dr Renton also participated in and presented at a focussed workshop on modelling resistance evolution at Rothamsted Research UK, and the Mathematical Modelling in Ecology and Evolution conference in Paris, and Dr Renton attended a focussed workshop on resistance evolution in Melbourne.

This research is supported by the Department of Education and Training Australian Postgraduate Award.

Design and evaluation of biosecurity surveillance systems

Project team: Dr Michael Renton[1] (leader; michael.renton@uwa.edu.au), Dr Maggie Triska[1], Assoc/Prof Ben White[1], Dr Jacky Edwards[2], Dr John Wainer[2], Dr Cassandra Collins[6], Dr John Weiss[2], Prof Roger Jones[1], Mr Andrew Taylor[3], Dr Lloyd Stringer[4], Dr Sarah Collins[3], Dr Sonya Broughton[3], Dr Kevin Powell[2]

Collaborating organisations: [1]UWA; [2]Department of Economic Development, Jobs, Transport and Resources Victoria; [3]DAFWA; [4]The New Zealand Institute for Plant and Food Research Limited; [5]Vinehealth Australia; [6]University of Adelaide

The overall aim of this project is to develop general methods for designing and evaluating statistically-based surveillance systems for high priority horticulture threats. The design and evaluation include testing the efficacy of the number and location of traps or samples, and the frequency with which they are conducted or checked. The methods will be applicable to evaluating both existing and new surveillance technologies for a range of industries and organisms.

The research focuses specifically on three case studies including two arthropod pests, grape phylloxera (Daktulosphaira vitifoliae Fitch) and Mediterranean fruit fly (Ceratitis capitate; Medfly) and one nematode pest, potato cyst nematode (Globodera rostochiensis; PCN). Methods for each organism integrate outputs from dynamic models simulating dispersal and spread of the organism in realistic landscapes, with systems that represent both static and dynamic surveillance systems, thus obtaining statistically-validated evaluation of the ability of surveillance strategies to meet detection goals.

One challenge faced in all case studies was how to use the available resources in the best way to maximise the chance of detecting a new biosecurity threat as quickly as possible. This is particularly important as these methods are also relevant to surveillance to help prove area-freedom or for monitoring. The recommendations will be provided to government regulators, property owners and horticulture managers to guide their surveillance efforts, improve time to detection and/or reduce costs, and thus restrict the spread of our case studies as efficiently as possible. All the case study pests pose significant threats to the industries they affect. They currently occur in some Australian states and regions and not in others, and this project integrates information from collaborators from multiple states in order to help restrict their spread within infected zones and reduce the chance of them spreading into new regions and states.

During 2015, models for all three case studies were developed, relationships with collaborators strengthened, and results presented at two international conferences (MMEE: Mathematical Models in Ecology and Evolution and MODSIM: International Congress on Modelling and Simulation). Surveillance techniques while sampling for grape phylloxera were used in Victoria where collaborators were assisted with a comparative study to test the efficacy of different surveillance methods.

Subsequently, field and modelling experiences were applied, with the knowledge of collaborators, to develop a local (within vineyard) spread model for phylloxera under varying environmental conditions.

This model, combined with multiple surveillance strategies, aims to optimise surveillance of phylloxera invasions and decrease the time to detection. A PCN network model was developed to assess both landscape and local scales. This model identifies at risk regions, for new PCN invasions, based on connectivity by roads, waterways, and trade, and will allow current and new surveillance strategies to be assessed. For the last case study, Medfly, a prototype model was developed and is currently being updated based on inputs from the collaborators.

This research is supported by the Plant Biosecurity Cooperative Research Centre.

Maggie Triska (UWA), Cassandra Collins (University of Adelaide) and Alan Nankivell (Vinehealth Australia) collect soil cores at a vineyard in Victoria AU to test for the presence of grape phylloxera. Photo: Michael Renton

National pathogen management modelling and delivery of decision support

Project team: Dr Michael Renton[1] (leader; michael.renton@uwa.edu.au), Dr Remi Crete[1], Prof Martin Barbetti[1], Dr Moin Salam[2], Dr Angela Van de Wouw[3,4], Dr Art Diggle[2]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]Marcroft Grains Pathology; [4]University of Melbourne

Plant pathogenic fungi cause severe damage, widespread losses, and are challenging to manage in agricultural systems. Farmers must allocate fields each year to different crops and choose among crop management options. These decisions are critical because they modify farm productivity and profitability in the short and long run.

Phoma stem canker (Blackleg) is a fungal disease that is one of the most damaging for Canola (oilseed rape). This disease is of major economic importance, causing yield losses of between 5% and 20% of production in some places, and even up to 100% in exceptional situations. Control strategies rely on fungicides, deep tillage of the crop residues, use of resistant cultivars, and crop management (specific sowing period, crop rotations).

However, rotation or stacking of resistance genes can potentially cause a super-virulent strain to arise because pathogens with a lot of virulence genes are likely to be selected. Strategies to maximise durability of resistance genes in cultivars should therefore both limit the selection of the more virulent variants of the pathogen and reduce pathogen population sizes.

Under what conditions different strategies will lead to the emergence of super virulent strains need to be considered, given the limited available space for infection and co-occurrence between strains. Previous work has focused on the effect of rotation strategies at the field scale assuming a homogeneous distribution of the crop and pathogen through a field.

The results highlighted the importance of using cultivar rotation strategies while pathogen virulence gene frequencies are still low. However, the model used in this previous study did not represent spatial variability in terms of cultivars grown. In effect, this meant it represented an isolated homogenous area (a field, set of fields, or landscape), and ignored the possibility of spatial heterogeneity within the area, or interactions with other fields outside the area.

This model was therefore extended in a spatially explicit manner (taking care of distances between fields) at a regional scale to investigate how different rotation strategies, degrees of co-ordination across a landscape, and levels of use of non-host crops influence evolutionary dynamics, population levels and the selection of super-virulent strains at the regional scale, and how this may be influenced by initial levels of pathogen, different proportions and different locations between the strains. This model is still under development, and will be used in the future for estimation purposes.

Concurrently, a new spatially implicit model has been built based on ordinary differential equations, describing the population dynamics of a fungal pathogen over a large agronomic region comprising a number of fields in which three kinds of crops are grown: one non-susceptible crop (neutral); one susceptible host crop with low resistance; and one susceptible host crop with high resistance. Different rates of rotations were compared to see what rotation strategies were optimal in maximising non-infected susceptible crop area and minimising infected crop area.

The results show that the best strategy is a more frequent rotation of infested crops into neutral crops than neutral crops into susceptible disease-free crops.

This research is supported by the GRDC.

Crop Genomics

Implementation of a newly developed fast generation technology for Australian crop breeding industry

Project team: Prof Guijun Yan[1] (leader; guijun.yan@uwa.edu.au), Dr Hui Liu[1], Dr Daniel Mullan[2], Dr Reg Lance[2], Dr Chunji Liu[3], Adj/Prof John Hamblin[1,4]

Collaborating organisations: [1]UWA; [2]InterGrain; [3]CSIRO; [4]SuperSeed Technology Pty Ltd

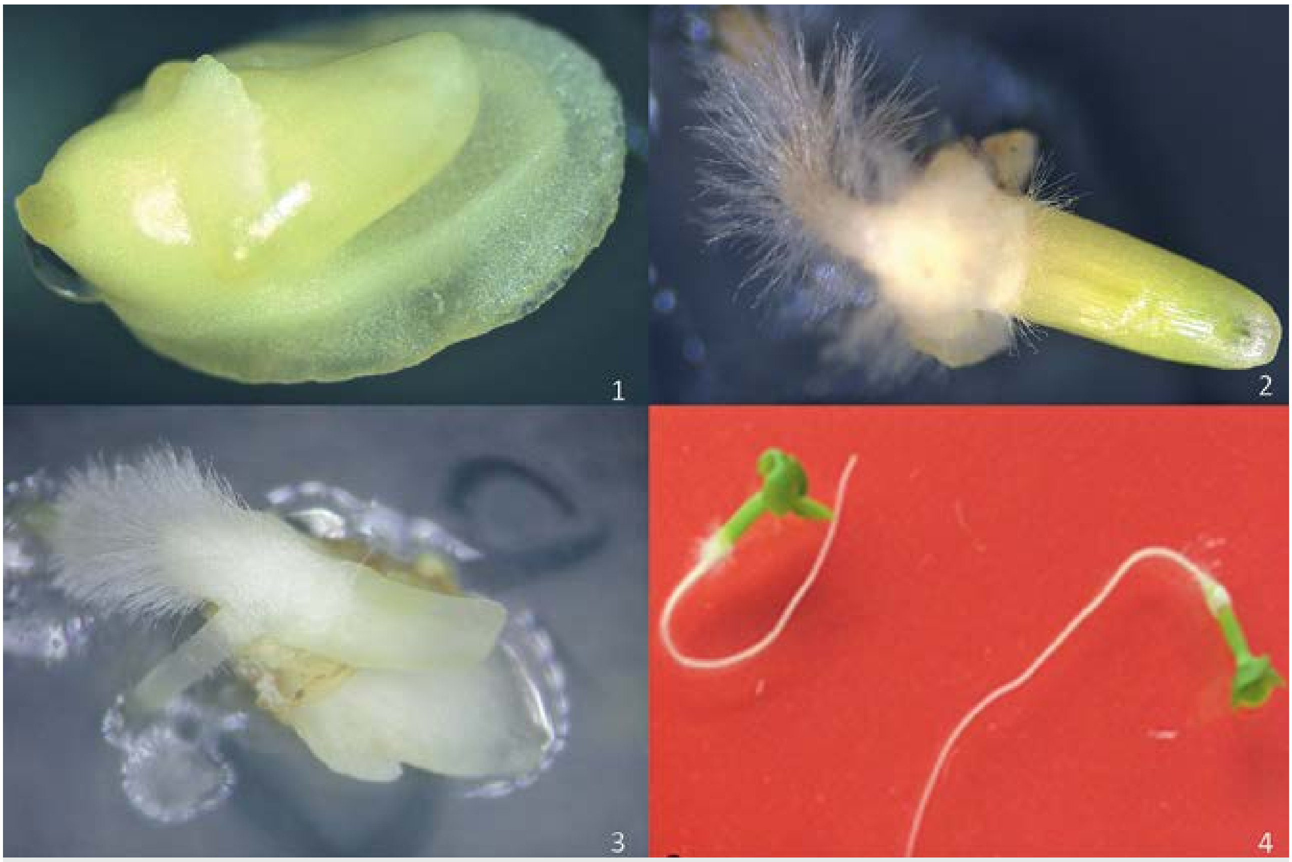
The aims of this project are to develop a reliable and fast generation system (FGS) on diverse wheat or barley genotypes, and to seek improvements to ensure the system is cost effective, reliable and widely adopted by crop breeding organisations.

FGS involves the culture of young embryos and plant management in a special environment. The total time for one generation can be 40-45 days enabling the turnover of eight to nine generations per year. This system is very useful to quickly produce populations of recombinant inbred lines (RILs) and near isogenic lines (NILs) for many areas of research.

In 2014 (project year 1), several RILs were developed using FGS for breeding industries. A new generation cycling system was tested completely under *in vitro* conditions and achieved *in vitro* flowering and seed-setting in selected wheat genotypes.

In 2015 (project year 2), the focus was to produce NILs targeting several QTLs regulating important agronomic traits. The FGS technology was extended with successful applications to a wide range of crops, including oat, rye, triticale, and canola.

One of the major achievements in 2015 include FGS incorporating molecular markers for the development of NILs. Two wheat populations (PHS1 and PHS2) segregating in pre-harvest sprouting (PHS) and one wheat population segregating in heat tolerance were chosen for development of NILs for each trait. Around 150 F2 seeds for each population were sown in early 2015. The molecular markers for the traits were developed. The heterogeneous inbred family (HIF) method was used to construct the NILs with FGS technology and molecular marker assisted selection. Each population was derived from the cross between two inbred lines. Hybrids heterozygous for the target QTL in F3 populations were chosen to self. From F3 onward, the progenies that were heterozygous at the target genome region were selected in each generation (Fig.1). Through these processes, the genetic background, except the targeted QTL, becomes homozygous by selfing. In F8 generation, the heterozygotes will



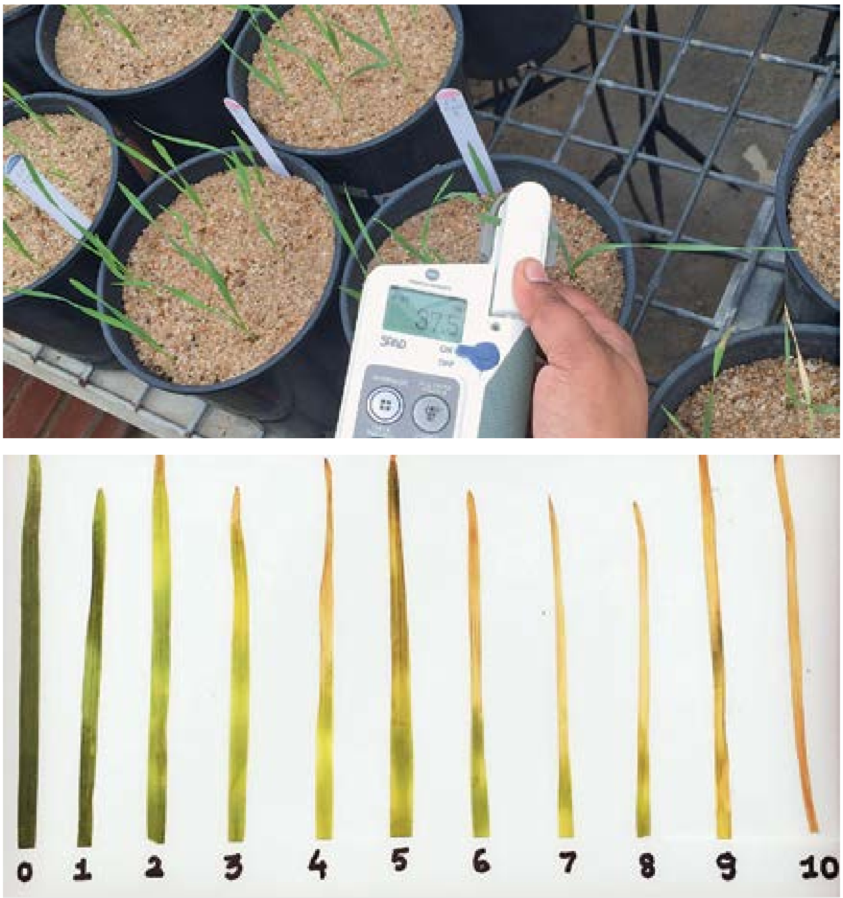
Young embryo culture for fast generation cycling in wheat, Triticale, oat and canola. 1. An embryo dissected from a young wheat seed; 2. A young Triticale embryo germinating on culture medium; 3. A young oat embryo germinating on culture medium; 4. Germinated young canola embryos ready for transferring into soil.

be selfed to produce pairs of isolines that are homozygous (either positive or negative) at the target genome region for gene identification.

Currently, F6 lines from each of the heterozygous F5 individuals for the NIL development are being generated. Ten to 20 NIL lines (F8) are expected to be developed for each of the traits (PHS and Heat tolerance) by early 2016.

Another major achievement in 2015 was the development and application of FGSin other crops. The possibility for application of FGS in other important crops including oat, rye, triticale, and canola was assessed. Selected cultivars in each crop were tested and FGS worked well in most of the tested cultivars.

This project is funded by the Council of Grain Growers Organisation (COGGO).



(a) SPAD chlorophyll content index (CCI) measurement and (b) visual senescence –the simplest and rapid techniques to measure chlorophyll levels in wheat seedlings after herbicide application.

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

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

Weeds are a major external factor causing serious yield and quality reduction in broad acre wheat production. Metribuzin ($C_8H_{14}N_4OS$) is a Group C herbicide and used to control broad spectrum weeds, but it incurs moderate damage in the majority of wheat cultivars. Higher tolerance to metribuzin is desired for effective weed management.

Investigating genetic diversity in large populations in search of better tolerant source requires a rapid screening technique. Firstly, phenotypic traits (such as SPAD chlorophyll content index (CCI), height, survival, visual senescence and shoot dry matter) reflecting phytotoxicity in wheat seedlings were monitored in the dose-response studies using eight metribuzin rate (0, 100, 200,

A tray system used for rapid herbicide phytotoxic assessment in large scale screening.

400, 800, 1600, 3200, 6400 g ai ha^{-1}) designed on logarithmic scale.

Sand was used as growth medium as it has no organic matter and with a pH>5, which provides optimum condition for effective metribuzin activity and thereby enhancing the rapidity of phytotoxic assessment.

SPAD CCI and visual senescence rated using a scale of 0-10, 16 days after treatment were found to be the most rapid and reliable traits to monitor decline in chlorophyll levels in wheat seedlings.

To test the metribuzin tolerance level in large scale screening (946 genotypes), a tray system was developed wherein uniform moisture (70% tray water holding capacity) was maintained in seedling tray (6 × 6 cells) throughout the experimental period. The screening involved two phases. Phase 1 (early stages of testing) was a partially replicated (*p*-rep) two-dimensional design, where 20% of entries were replicated twice and checks (tolerant/ susceptible genotypes) were replicated thrice to determine spatial error parameters.

The predicted SPAD CCI values obtained from phase 1 spatial models were ranked and 25+25 top and bottom ranked genotypes expressing considerable tolerance and susceptibility were selected for two-dimensional full replication (*f*-rep) design with four replicates to confirm and identify highest source of tolerance and susceptibility. These genotypes will be used for genetic studies to identify QTLs responsible for metribuzin tolerance.

This research is supported by the Australia postgraduate award (APA).

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

Project team: Prof Guijun Yan[1] (leader; guijun.yan@uwa.edu.au), Ms Xingyi Wang[1], Dr Hui Liu[1], Hackett Prof Kadambot Siddique[1]

Collaborating organisations: [1]UWA; Agricultural University of Hebei

Pre-harvest sprouting (PHS) can cause severe damage to the quality and production of wheat, which is the major cultivated and exported grain crop in Australia. PHS is a phenomenon whereby un-harvested wheat grains germinate or sprout on the plant in the field when they encounter rain or air-humidity close to saturation.

PHS is considered a lack of seed dormancy which is a quantitative trait regulated by several genes or QTLs and affected by environmental factors. One of the most important genes for PHS resistance is consistently identified on the long arm of chromosome 4A. A closely linked maker ZXQ118 for the 4AL PHS gene has been developed.

To identify the major 4AL gene(s), this study is developing near-isogenic lines (NILs) using the ZXQ118 maker. An embryo-culture based fast generation system is used to shorten the developing period. Transcriptome analysis done on the NIL pairs will identify the major 4AL gene(s) responsible for PHS resistance.

Except for the major gene on 4AL, QTL analysis has identified many loci on other chromosome arms from different cross populations. In particular, two major QTLs on chromosomes 3A and 4B have been repeatedly identified in different research. This study uses the closest makers available for the reported PHS QTLs (Xgwm155 for 3AL and Xgwm495 for 4BL) to screen 42 Australian wheat cultivars with known PHS phenotyping data in National Variety Trial (NVT).

So far, NIL has been developed to F6 lines from the heterozygous F5 individuals using the ZXQ118 marker. Screening Australian wheat cultivars using reported SSR marker and data analysis with their PHS phenotyping has been done.

This research is supported by the Yipti Foundation: Research Awards and Grants-in-Aid.

Pre-harvest sprouting of wheat cultivar Westonia.

Animal breeding is based on F1 recurrent selection, and these ewes in the field at West Dale, WA, are all F1's. Canola breeding, represented by the large field trial in the canola field at rear, is normally based on selection among near-homozygous selfed progenies.

Pre-breeding of selfing crop plants for long-term genetic gain and optimal value from molecular genetics technology

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

Collaborating organisations: [1]UWA; [2]NPZ Australia Pty Ltd; [3]NPZ Lembke, Germany

The IOA crop genetics and breeding team is re-inventing plant breeding for selfing crop plants through a new approach based on the animal model. The team is researching S0 (F1) recurrent selection to provide long-term genetic gain with minimal inbreeding.

Typically, selfing crops lose genetic diversity as a result of crossing after selfing and formation 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 with optimal contribution selection. 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. Genetic diversity is retained, the rate of inbreeding can be controlled and the potential for long-term genetic gain is increased. Pure lines will "spin off" from this rapid early generation crossing program. 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 method promises to improve the long-term value of new molecular genetics technology in crop breeding, because it provides a reliable source of genetic diversity for exploration and exploitation, with minimal loss of alleles due to genetic drift.

This research is supported by NPZ Australia Pty Ltd.

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

Project team: Mr Yaseen Khalil[1] (PhD candidate; yaseen.khalil@research.uwa.edu.au), Dr Ken Flower[1], Hackett Prof Kadambot Siddique[1], Dr Phil Ward[2], Dr Colin Piggin[3]

Collaborating organisations: [1]UWA; [2]CSIRO; [3]ACIAR; [4]Murdoch University

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 and overseas, it is important to understand the factors, such as stubble and rainfall, which influence the efficacy of pre-emergent herbicides in Western Australia.

This research has three main objectives; to determine the effect of rainfall amount and intensity on leaching of trifluralin, pyroxasulfone and prosulfocarb from stubble, to investigate the effect of crop residue type (i.e. crop type) and level of degradation (age) on sorption and leaching from stubble of trifluralin, pyroxasulfone and prosulfocarb, and to determine the effect of residue height, amount and orientation on pyroxasulfone interception, leaching and distribution in the soil (i.e. water movement down the standing stubble) and weed control efficacy.

An initial series of experiments was conducted to develop a bioassay methodology for assessing the concentration of trifluralin, pyroxasulfone and prosulfocarb present in both stubble and soil. This included selecting suitable bioassay species (annual ryegrass and cucumber) and then chemical analyses of these herbicides in soil and crop residue samples, which was done in collaboration with Murdoch University using GCMS/MS.

Following the bioassay, another set of experiments was carried out to investigate how much herbicide was intercepted and retained by wheat residue. The experiments investigated the three herbicides with four different rainfall amounts (0 – 20 mm), three different intensities (5 – 20 mm/hr), and five application times (immediately after spraying herbicide – 14 days).

As expected, increased amounts of rainfall leached more herbicide from the stubble onto the soil and the sooner the rainfall occurred the more herbicide was leached. However, the intensity of rainfall had no significant effect on leaching of the herbicides from the crop residue into soil.

This research is supported by ACIAR's John Allwright Fellowship.

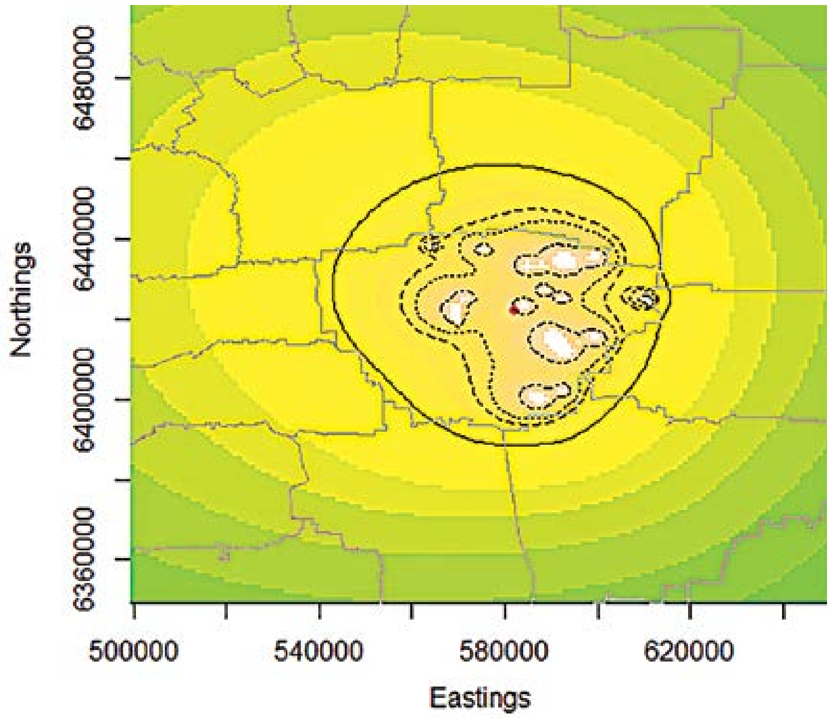
Predicting spread of skeleton weed to help inform surveillance and eradication

Project team: Dr Michael Renton[1] (leader; michael.renton@uwa.edu.au), Dr David Savage, Mr Andrew Reeves[2]

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

Skeleton weed is currently spreading across the Western Australian grain-growing region and poses a serious threat to agricultural production in areas that it infests. Therefore, the Department of Agriculture and Food Western Australia has instigated aimed at containing the weed within the few shires where it already well-established and eradicating it in any other shires where it is found.

Response of bioassay plant species to different herbicide rates (g/ha) in two germination mediums. Photo: Yaseen Khalil



Risk map generated by skeleton weed spread model

The development of a model able to simulate and predict the spread of skeleton weed was commissioned by the Department of Agriculture and Food Western Australia and the Grains Seed and Hay Industry Management Committee (GSHIMC), with the idea that better prediction of the direction and distance of spread of the model from known infestations would allow better targeting of surveillance efforts. This would in turn improve chances of finding new infestations and achieving eradication and/or containment.

In 2015 a detailed model of the wind-dispersal of skeleton weed seeds was constructed. Hourly wind data for four shires of prime concern was obtained from DAFWA weather stations and locations of known infestations and estimates of infestation sizes were obtained from DAFWA databases for Corrigin shire. As a proof of concept, this data was used as input into the model to produce risk maps for Corrigin and adjoining shires.

Additional modelling investigations showed that timing of seed release within a day and within a month could both have a significant impact on predicted spread patterns, due to the different wind speeds and directions. Based on these results, additional field trials have been conducted to better understand at what time of day and on what days of the year seed release and dispersal is most likely to occur.

This research is supported by DAFWA and Grains Seed and Hay Industry Management Committee (GSHIMC).

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

Project team: Prof Andy Whiteley[1] (leader; andy.whiteley@uwa.edu.au), E/Prof Lynette Abbott[1], Dr Abul Hashem[2], Mr Paul Storer[2], Dr Zakaria Solaiman[1]

Collaborating organisations: [1] UWA; [2]DAFWA; [3]Australian Mineral Fertilisers

The complex bio-physical interactions associated with herbicide efficacy in agricultural soils managed to maximise microbial ecosystem services linked to nutrient use efficiency are being investigated.

The research commenced by sampling soil from existing trial sites of the DAFWA at Merredin. After 14 years of continuous glyphosate application, herbicide resistance to glyphosate in annual ryegrass had been confirmed and evolution of a diverse range of weed species has occurred which also corresponded with changed soil properties and microbial communities. At a second site, where lime and herbicides were applied over five years, have also changed with these treatments.

Soil biological processes and microbial diversity are being investigated with following application of novel mineral fertilisers to soils with different herbicide use histories.

In addition to the sampling of the long-term field trials, two glasshouse trials were conducted in 2015 using same soils from the field experiments. The aim was to determine whether the history of herbicide use had influenced soil microbial communities and their functions.

Soil biological processes and microbial diversity are also being investigated with following application of novel mineral fertilisers to soils with different herbicide use histories.

A new field trial was established in 2015 at Dowerin with the following herbicides treatments: (i) Nil herbicide, (ii) Glyphosate only, (iii) Glyphosate + Sakura, (iv) Glyphosate + Glean, (v) Glyphosate + Bromooxynil, and (vi) Glyphosate + MCPA) along with nil fertiliser, novel mineral fertiliser and standard chemical fertilisers replicated four times. In this experiment, soil biological processes are being assessed as for the long-term field experiments.

This research was supported by the ARC.

Management of microorganisms to unlock the phosphorus bank in soil

Project Team: Dr Deirdre Gleeson[1] (leader; deirdre.gleeson@uwa.edu.au), Prof Daniel Murphy[1], Asst/Prof Suman George[1], Mr Pu Shen[2], Prof Xu Minggang[2], Dr Chris Guppy[3], Dr Richard Flavel[3], Terry Rose[4]

Collaborating organisations: [1] UWA; [2]Chinese Academy of Agricultural Sciences (CAAS); [3]University of New England; [4]Southern Cross University

The overall aim of this project was to provide grain growers with management options that harness soil microorganisms to unlock part of the $10 billion worth of fixed phosphorus (P) in Australian arable soils and to use P more efficiently.

The productivity of the Australian grains industry depends on the small zone of soil surrounding roots, known as the rhizosphere. Nutrient uptake by plants is strongly influenced by nutrient dynamics in the rhizosphere and by the interaction between roots, microorganisms and mineral particles that occur in this zone in the soil. Despite the importance of the rhizosphere, we know very little about rhizosphere processes and in particular how to manipulate the rhizosphere to benefit productivity.

The aims were to improve understanding of the mechanistic basis of rhizosphere strategies for enhancing P mobilisation in order to optimise P use within farming systems, and provide the agricultural sector with management options that harness soil microorganisms to unlock part of the $10 billion worth of fixed P in Australian arable soils and use P more efficiently.

A number of laboratory based experiments to assess how management of soil biology, legume rotations and soil structure (e.g. till vs no till) could improve P cycling in Australian soils.

The focus for 2015 was the final laboratory work in this project. Dr Deirdre Gleeson travelled to Armidale in New South Wales to visit collaborators Dr Chris Guppy and Dr Richard Flavel at the University of New England (UNE). In this work both intact and re-packed soil cores with P fertiliser granules were amended to visualise how pore connectivity in the soil environment and interactions

Soil core being scanned at the UNE cat scanning facility. Photo: Richard Flavel between roots and microbes affects fertiliser P release.

The results showed that sieving and re-packing soil into cores has a large effect on mobilisation of P and by spatially mapping the concentration of P around the granule, we have been able to capture how much soil the fertiliser influences, and how root systems respond to that.

The combined approach of characterising the soil, plant and microbial systems at the same time will help to elucidate how these systems interact in the field and how we might manage the rhizosphere to improve crop productivity. This work is currently being prepared for submission.

This project wrapped up at the end of 2015 and resulted in two manuscripts published, a further three manuscripts under review and ten extension articles. Work from the project was presented at both National and State Conferences as well as regularly at GRDC Soil Biology Initiative II Meetings, workshops and conferences.

This research was supported by the GRDC and the ARC.

Managing biological, physical and chemical constraints to soil carbon storage

Project Team: Dr Deirdre Gleeson[1] (leader; deirdre.gleeson@uwa.edu.au), Prof Daniel Murphy[1], Assoc/Prof Peta Clode[1], Dr Yoshi Sawada[1], Dr Hazel Gaza[1], Dr Frances Hoyle[1], Mr Chris Gazey[2], Dr Clayton Butterly[3], Prof Cixian Tang[3], Dr Samantha Grover[3], Dr Lynne Macdonald[4], Dr Jeff Baldock[4]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]La Trobe University; [4]CSIRO

Sustainable management of soil carbon (C) is essential for the continued viability of Australian agriculture. This project aims to provide options to overcoming constraints to C storage in coarse-textured agricultural soils. It builds on the Federal Governments previous Soil Carbon Research Program (SCaRP) Western Australian component which highlighted that the surface soil layer (0–10 cm) of many Western Australian agricultural soils were largely saturated and that if further gains in soil C storage are to be made then soils at depth (10–30 cm) need to be targeted.

The project will assess the potential to increase soil C via management practice through existing practices such as claying and liming (i.e. increasing pH), and emerging practices such as one-off soil inversion using mouldboard ploughing or spading.

During 2015 the research focussed on laboratory work to support the field work completed during 2014. The impact of pH on microbial successional patterns where plant residues with different underlying nutritional and chemical characteristics are applied, was investigated. State of the art DNA sequencing was used and combined with an analysis of the microbial functions responsible for soil organic matter decomposition, specifically key enzymes (e.g. laccase and cellobiohydrolase) associated with this process, to help understand microbial succession during plant residue decomposition.

Findings to date indicate that during decomposition microbial community composition and function change predictably over time and differed between residue types applied. This work will aid in the development of more comprehensive ecological models of microbial succession and improve understanding of the processes that regulate soil carbon cycling.

With colleagues at La Trobe University an experiment to better understand how the increase in pH due to liming impacts upon C mineralisation was also designed. In particular, it aimed to quantify, over a lime-induced pH gradient the mineralisation of soil organic matter, the mineralisation of a newly added plant residue and the interaction between the mineralisation of added plant residue and the existing soil organic matter (the priming effect). The research further aimed to determine whether mineralisation was related to the abundances of key soil microbial populations and their functions with respect to soil organic matter decomposition.

Work from both research experiments was presented at the WA Branch Soil Science Meeting in Mandurah in September.

This research is supported by the Australian Federal Government's Department of Agriculture and Water Resources.

Does increasing soil carbon in sandy soils increase soil nitrous oxide emissions from grain production?

Project Team: Dr Louise Barton[1] (leader; louise.barton@uwa.edu.au), Ms Debra Donovan[1], Mr Chris Swain[1], Prof Daniel Murphy[1], Dr Frances Hoyle[1], Dr Craig Scanlan[2], Prof Klaus Butterbach-Bahl[3]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]Institute of Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU); Liebe Grower Group, National Australian Oxide Research Program, Karlsruhe Institute of Technology

Crop production is often a source of greenhouse gas (GHG) emissions including nitrous oxide (N_2O), which is almost 300-times more potent than carbon dioxide (CO_2). Agricultural soils can also be as a sink for CO_2 via soil C sequestration. However, increasing soil carbon via tillage practises can alter soil GHG emissions depending on the soil type.

Dr Deirdre Gleeson (UWA) and Mr Chris Gazey (DAFWA) collecting soils for laboratory incubation experiments from historical lime trials at Wongan Hills. Photo: Yoshi Sawada

Understanding the effect of increasing soil carbon is critical when assessing the effectiveness of soil C sequestration to abate GHG emissions from the agricultural land sector. Our knowledge of GHG emissions from cropped soil is largely derived from agricultural systems in the Northern Hemisphere, and their applicability to southern Australian cropping systems is poorly understood.

The aim of this study was to investigate if increasing soil organic carbon increases N_2O emissions from a cropped soil in the Western Australian grainbelt (Buntine) by measuring emissions for 2.5 years using automated chambers. This project was completed in 2015 and after completed collecting 2.5 years of N_2O emissions data.

Increasing soil organic carbon increased total N_2O emissions at Buntine, with greatest emissions occurring following summer and autumn rain. However, after 2.5 years of measurements the annual emissions remain low (0–0.27 kg N_2O-N ha-1 yr-1) by international standards, and less than 0.12% of the nitrogen fertiliser applied. Globally, and across a variety of climatic regions, annual N_2O losses from cropped mineral soils have ranged from 0.3 to 16.8 kg N_2O-N ha-1 yr-1. The annual N_2O emission reported for Buntine is also within the range of values that have we have previously reported for two other study sites in the Western Australian grainbelt.

This research was supported by the GRDC and Australian Government.

Mitigating the Greenhouse Gas Potential of Australian Soils Amended with Livestock Manure.

Project team: Dr Sasha Jenkins (leader; sasha.jenkins@uwa.edu.au)

Applications of manures to soil can improve soil quality, biological activity and crop performance as well as provide a sustainable option for the re-use of agricultural waste. However, if applied inappropriately they can have little or no benefit and result in greenhouse gas (GHG) emissions, especially nitrous oxide (N_2O). Developing effective mitigation strategies for reducing N_2O emissions from soils amended with manure requires a better understanding of the microorganisms and mechanisms involved.

This project evaluated the effectiveness of different manure storage systems (stockpiled, composted or pelletised manure) and application methods (lower application rate, dry seeding, broadcast or incorporated into the soil) at reducing N_2O emissions; and investigated the relationship between N_2O emissions and nitrifier and denitrifier populations following manure amendment.

A series of laboratory and field studies in Western Australia found that the effectiveness of a GHG abatement method is dependent upon both manure type and soil type.

Applying composted manure to land greatly reduced N_2O in clayey soils whereas pelletised manure was a more successful at mitigating GHG in sandy soils. Thus, composting and pelletising manure are good strategies for decreasing soil GHG emissions in semiarid regions, where the emissions result from denitrification or nitrification. Adopting the low-cost, simple application methods of dry seeding, incorporation and a lower application rate of less than 5 t ha^{-1} are also effective mitigation strategies.

The research outcome is the development of low-cost mitigation strategies that can decrease national livestock emissions with minimal impact on productivity and profitability.

This research was supported by DAFF Filling the Research Gap.

Building soil carbon in cropping systems and impact on greenhouse gas emissions using cattle feedlot compost

Project team: Dr Zakaria Solaiman[1] (leader; zakaria.solaiman@uwa.edu.au), E/Prof Lynette Abbott[1], Mr Steve Jones[2]

Collaborating organisations: [1]UWA; [2]WA Lot Feeders' Association (WALFA)

The aim of this research was to investigate the potential for soil carbon sequestration and mitigate greenhouse gas emissions in relation to the soil amendments over several years. On-farm trials of cattle feedlot manure amendment at two feedlot enterprises in the WA grainbelt were conducted. Application of composted manure is an uncommon practice in this region.

These on-farm trials are investigating the soil carbon following application of composted feedlot manure compared with use of stockpiled manure in comparison to district fertiliser practice. Most feedlots grow grain or silage for cattle feed and providing opportunity for establishing a closed loop system. The two farms selected currently compost their feedlot manure and apply it within their cropping operation.

The project uses this compost in comparison to the uncomposted manure. Both treatments have urea only or urea and compound fertiliser applied during seeding. The district practice of seeding with just urea and compound fertiliser is included as the control.

Grain yield significantly differed between the two trial sites. Grain

Field studies found that the effectiveness of a GHG abatement method is dependent upon both manure type and soil type.

Building soil carbon in cropping systems using cattle feedlot compost.

yield at one site was significantly increased by application of both manure and compost in combination with urea and the composite fertiliser. In contrast, grain yield was not significantly affected by treatments at the other feedlot site.

As this is the first year of the trial, application of manure and compost was not expected to significantly increase on grain quality assessed as grain N and protein content due residual effects of fertiliser application from previous years. As expected, no significant differences were observed in N % and protein % in grain from the site were plant growth responses were recorded.

Gas samples (N_2O, CH_4 and CO_2) were collected after imposition of treatments at both field sites, and immediately following the two main rain events which occurred during the growing season. There were no manure or compost treatment effects on gas fluxes at either field site in 2015.

This research was funded by the Australian Government's Department of Agriculture.

Least Cost GHG Abatement – Opportunities in Australian Grain Farms

Project team: Dr Peter Thorburn[2] (leader; peter.thorburn@csiro.au), Dr Marit Kagt[1], Mr Jody Biggs[2], Dr Elizabeth Meier[2], Ms Nikki Dumbrell[1]

Collaborating organisations: [1]UWA; [2]CSIRO; GRDC; Ag Research Limited New Zealand; Ag Alliance

This project estimates the net, whole-farm greenhouse gas (GHG) mitigation balance, including soil carbon sequestration, of various management practices applicable to Australian grains farms, taking into account the trade-offs and/or interactions associated with farming practicalities and economics.

QLD Brigalow – wind shade of tree belt on crop production. Photo Marit E. Kragt

The project determined a set of management practices that are relevant on six case study farms in WA, QLD and VIC/SA. We used the APSIM model to simulate the net GHG mitigation for each management practice.

Whole-farm economic data and gross margins information was collected to undertake an economic analysis of the profitability of each management scenario. A whole-farm economic model has been developed (in R), with analyses underway (to be finalised in 2016).

Thus far, limited opportunities for Australian grain farms to sequester carbon in their soils have been found because practices that maximise soil carbon can reduce farm profitability or fit poorly within the overall practicalities of farm management.

This research is supported by the Australian Government Department of Agriculture, Fisheries and Forestry and the GRDC.

Crop Genomics

Project team: Prof Dave Edwards[1] (leader; dave.edwards@uwa.edu.au), Prof Jacqueline Batley[1] (leader; Jacqueline.batley@uwa.edu.au), Dr Philipp Bayer[1], Ms Bhavna Hurgobin[1], Ms Mahsa Mousaviderazmahalleh[1], Dr Pradeep Ruperao[1], Mr Juan Montenegro[1], Dr Kenneth Chan[1], Dr Agnieszka Golicz[1], Dr Paul Visendi[1], Dr Paula Martinez[1], Ms Jenny Lee[1], Mr Andy Yuan

Collaborating organisations: [1]UWA; [2]International Pea genome sequencing consortium, [3]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 2016.

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.

This research is supported by ARC and the GRDC.

Plant information systems

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

Collaborating organisations: [1]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.

The research is supported by the Australian Government's Australian National Data Service.

Long term no-till farming systems

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

Collaborating organisations: [1]UWA; [2]Western Australian No-Tillage Farmers Association (WANTFA); [3]CSIRO

This GRDC funded long term no-till trial was started in 2007 and has been refunded until June 2019. This study is investigating the agronomic and economic costs and benefits of using diverse crop rotations, residue retention and minimal soil disturbance over time. Other practices being tested in this cropping systems trial are tramlining to reduce compaction, windrow burning for harvest weed seed management and tillage.

Differences in gross margin between rotations were greatest in the wetter seasons, where continuous wheat had the lowest gross margin compared with more diverse rotations. The trial also showed that cover crops did not increase the performance of following cash crops under typical central grainbelt conditions.

High residue levels improved the establishment of canola under dry conditions, but reduced yields in situations where the seeder could not cope with the stubble. Residue also had little impact on soil water storage over summer, but was shown to increase soil water in the early part of the growing season. The trial showed that crop residue needs to be carefully managed to realise the full benefit.

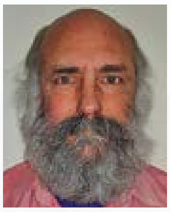
This research is supported by the GRDC.

Seeding between the stubble rows with the NDF disc seeder. Photo: Ken Flower.

2

Sustainable Grazing Systems

Theme Leaders:



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Sustainable grazing systems are essential to provide feed for the various animal production systems in Western Australia. These fall into two main type: extensive rangeland systems and mixed crop-pasture systems. UWA has been actively researching the crop-pasture and animal production nexus based on its own active research capability and in close cooperation with other national and international Research, Development, Extension and Adoption (R,D,E and A) partners.

Mixed crop-pasture systems are largely sheep based in WA with a smaller cattle component. The feed base is dominated by the use of annual pastures, predominantly subterranean clover. Although a large range of new annual legumes are now also available. There is also a growing interest in perennial systems particularly in the marginal areas; for instance, pasture cropping which exploits the different growth patterns between a winter-active crop and a summer-active perennial pasture and the incorporation of shrubs, including natives, into annual pastures.

Components of the system that can be improved include aspects of pasture improvement and crop- pasture management and animal production. UWA with partners has recently been particularly active in sub-clover pre-breeding through the establishment of a sub-clover core collection, the sequencing of the sub-clover genome, and the identification of c. 10,000 single-nucleotide polymorphism markers – all as part of an extensive genetic/genomic platform for future improvement.

UWA also has a current focus on development of phosphorus efficient pastures that can maintain productivity on lower soil phosphorus levels. Within the system the interaction of pasture and crop are critical to the possible management of weeds, including herbicide resistant weeds, because within the pasture phase there is a clear pathway to their management, which supplements options in can improve sustainability of cropping. Aspects of efficient nutrition use and disease control also show promise to alleviate issues that are problematic in the cropping phase alone.

Rangelands systems are extensive and 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.

The Sustainable Grazing Systems Theme will focus on the contribution of livestock industries to the solution to global food supply. Grazing systems need to be sustainable, which means several problems need to be addressed including i) consumption of human food by livestock; ii) livestock species and genotypes poorly adapted to the local environment; iii) poor animal health and welfare resulting in sub-optimal productivity; iv) provision of adequate animal nutrition; v) environmental footprint.

Biserrula pelecinus is tested for antimethanogenic properties.

Methane-fighting forages

The mechanism of antimethanogenic bioactivity of plants in the rumen

Project team: Prof Phil Vercoe[1] (leader; philip.vercoe@uwa.edu.au); Assist/Prof Zoey Durmic[1], Dr Joy Vadhanabhuti[1], Dr Chris McSweeney[2], Mr Jagadish Padmanabha[2], Mr Bidhyut Banik[1], Assoc/Prof Gavin Flematti[1], Ms Azizah Algreiby[1]

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

Plants contain secondary compounds with antimicrobial properties that have the potential to reduce methane emissions from ruminants. This project aims to extract and fractionate these compounds, to identify specific compounds that reduce methane emissions, and to improve our understanding of the mechanisms behind their action. Using chemical fractionation and *in vitro* fermentation assays (batch and continuous culture), we have gained an indication of the antimethanogenic and general antimicrobial effects of the plant species.

Several types of bioactive compounds appear to be responsible for the antimethanogenic effects and they have been isolated, identified and tested further. Some antimethogenic effects persist over two weeks in an artificial rumen, the 'Rusitec'. Molecular and biochemical analyses have enabled us to reveal some mechanisms by which these compounds affect the rumen microbes. Dose responses for these compounds and the effect of the type of substrate have been investigated, leading to identification of the best approach and combinations of compounds for evaluation in animals, and this work will show whether the effects can be replicated *in vivo*. If they are successful, we will be moving towards the provision of novel tools for mitigating methane emissions by ruminants.

The final report for this project was submitted in July 2015 and there are now plans underway to investigate some of the compounds we have identified in animals housed in the animal house.

More information is available at www.mla.com.au/Research-and-development/Environment-sustainability/National-livestock-methane-program and http://www.livestockmethane.info:8080

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

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

Project team: Dr Julian Hill[4] (leader; upweyag@optusnet.com.au), Dr Dean Revell[2], Prof Phil Vercoe[1], Dr Joe Jacobs[3]

Collaborating organisations: [1]UWA; [2]CSIRO; [3]Victoria DPI; [4]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. We are demonstrating the advantages over the 'business as usual' scenario of ryegrass-only systems, and showing how producers can transition to a low emissions system while improving productivity.

The integration of the correct choice of perennial shrubs with antimethanogenic properties into ryegrass–lucerne systems is expected to reduce emissions intensity (kg methane per kg meat) while increasing farm profit through increased growth rates and earlier slaughter.

Normally, sheep production in eastern Victoria is based on perennial ryegrass with supplementary grain feeding in the feed gap in summer and lucerne for hay production and grazing. These systems are generally located on low fertility, fragile soils. The farming systems are not suited to integration of annual legumes that have been demonstrated to abate methane emissions (e.g. biserrula) and are based on perennial pasture production. A feasible option to protect these soils from erosion is the use of integrated perennial shrub–legume farming systems that increase individual animal production as well as whole-farm performance. Shrubs have been planted on the site in Victoria and samples have been taken and tested *in vitro*. Some of the shrubs did not establish but those that did were fed to sheep and the methane they emitted was captured and measured using an in-field polytunnel system. The results are being analysed to establish whether sheep grazing the shrubs produce less methane.

This project is funded by the Australian Government's Department of Agriculture and Water Resources.

Best choice shrub and inter-row species

Project team: Prof Phil Vercoe[1] (leader; philip.vercoe@uwa.edu.au), Dr Dean Thomas[2], Dr Dean Revell[2], Dr Kirrin Lund[1], Mr Nathan Phillips[2], Dr Frances Phillips[3]

Collaborating organisations: [1]UWA; [2]CSIRO, [3]University of Wollongong

Combinations of shrubs and pasture species that are selected for their nutritive value and antimethanogenic bioactivity offer a practical means for reducing methane emissions and emissions intensity in grazing livestock. Moreover, recent bioeconomic modelling has indicated shrub-based systems, established over a modest 10 to 20% of a mixed farm, could increase whole-farm profit and reduce business risk.

Sheep grazing on antimethanogenic pastures.

These positive benefits could all be enhanced if the choice of both shrub and inter-row pasture species was made with the dual purpose of reducing emissions directly (i.e. antimethanogenic properties) and improving emissions intensity (i.e. improving the nutrition of grazing livestock). In this project, shrubs selected for either their biomass production or antimethanogenic properties, then planted with antimethanogenic pasture inter-rows, are being compared to various pasture grazing scenarios that could be incorporated into farming systems. The productivity and in-field methane emissions of animals grazing these systems are being measured during the autumn feed gap.

During the period of the project, two grazing experiment were undertaken and the results demonstrated that the integration of shrubs into a grazing system can improve animal productivity during the autumn feed-gap when feed-on-offer is traditionally scarce and of low quality. Perhaps one of the most significant benefits of the shrubs was that they reduced the need to supplementary feed the sheep during that time of year, which can be a costly exercise for producers. The grazing system that included shrubs reduced the emissions intensity of sheep by approximately 25% during that time of year. The final report was submitted in July 2015 and should be available on the government website.

More information is available at www.mla.com.au/Research-and-development/Environment-sustainability/National-livestock-methane-program and http://www.livestockmethane.info:8080

This research is funded by the Australian Government's Department of Agriculture and Water Resources and MLA.

Nitrate and sulphate rich shrubs to reduce methane and increase productivity

Project team: Dr Hayley Norman[2] (leader; hayley.norman@csiro.au); Prof Ed Barrett-Lennard[1], Assoc/Prof John Milton[1], Prof Phil Vercoe[1]

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

Feeding nitrate and sulphate to ruminants is a proven strategy for abatement of methane emissions but, in extensive systems, provision of such supplements can be problematic because individual animals can select an inappropriate dose leading to a risk of toxicity. However, a number of drought-hardy Australian native shrub species accumulate significant concentrations of nitrate and sulphate, and farmers plant several of these species as forage in the low-to-medium mixed crop–livestock zone. This project aims to quantify the potential of these shrubs to offer a safe, profitable, environmentally positive and 'natural' means of reducing methane emissions from sheep grazing cereal stubbles by incorporating them into grazing systems in the mixed crop–livestock zone.

At two field sites a range of different shrub species have been established, and at each sampling time there were significant differences in edible dry matter (EDM) and nutritional value between the accessions. The *Atriplex* and *Rhagodia* species were the most productive, whereas growth of *Eremophila glabra* was limited. Material from all sites has been analysed for nutritional value, and anions such as nitrate, chloride and oxalate are being measured. The majority of *A. nummularia*, *Rhagodia preissii* and *Eremophila glabra* shrubs produced EDM that would at least meet the maintenance requirement of mature animals in terms of energy and crude protein. Species with poor digestibility of organic matter (OMD) included *Atriplex amnicola, A. rhagodioides* and *Maireana brevifolia.*

We have also completed a benchmarking study of the potential of these shrubs to offer a safe, profitable, environmentally positive and 'natural' means of reducing methane emissions from sheep grazing cereal stubbles in the low-to-medium rainfall zone of southern Australia. We found that sheep either grew or maintained live weight and there was little evidence that the shrubs induced nitrate toxicity.

This research is supported by the Australian Government's Department of Agriculture and Water Resources and AWI.

Cranbrook research site_Nitrates.

Efficient livestock with low emissions (ELLE) from southern grazing systems

Project team: Prof Phil Vercoe[1] (leader; philip.vercoe@uwa.edu.au), Assist/Prof Zoey Durmic[1], Dr Joy Vadhanabhuti[1], Mr Bidhyut Banik[1], Dr Hayley Norman[2], Dr Xixi Li[2], Dr Alan Humphries[3], Mr David Peck[3]

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

This project has generated information on fermentability and methanogenic potential, using a range of variables, for key pasture species in Australia that can be use in modelling to predict their contribution towards animal production and greenhouse gas emissions. All samples from the annual and perennial species in the project have been grown, collected and tested using an *in vitro* fermentation system and analysed by near-infrared (NIR) spectroscopy. The data for biomass, nutritive value and *in vitro* fermentation characteristics are now available for use in modelling projects and NIR calibration equations have been developed that will be extremely valuable as tools for predicting pasture quality and for informing management decisions.

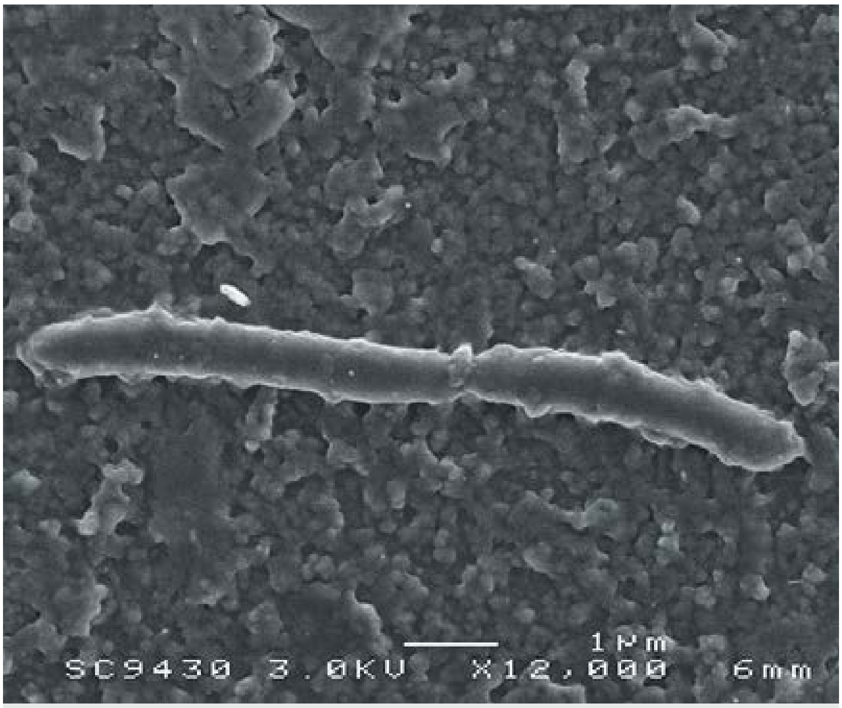
The main outcomes from the work have been: 1) have quantitative measurements of the variability in the agronomic, nutritional and rumen fermentation characteristics of plants

Portable accumulation chambers and a flame ionisation detector were used to measure 1-hour of methane from each sheep.

that are suitable for southern grazing systems. This variability means there is plenty of scope to make better choices about species and varieties to improve the amount and quality of feed for a longer period of time. Making better choices will improve productivity and emissions intensity of our southern grazing systems. 2) NIR calibration equations that could help develop a powerful tool for obtaining more accurate and real time estimates of nutritional value of pastures in the field to assist in making better, more timely, grazing management decisions.

The final report for this project was completed in July 2015. More information is available at www.mla.com.au/Research-and-development/Environment-sustainability/National-livestock-methane-program and www.livestockmethane.info:8080

This project is supported by the Australian Government's Department of Agriculture and Water Resources and MLA.



Rumen bacteria under electron microscope.

Host control of methane emissions from sheep

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

Collaborating organisations: [1]UWA; [2]NSW-DPI; [3]University of New England; [4]University of Queensland; [5]CSIRO; [6]AgResearch, New Zealand; [7]Utah State University, USA; [8]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 host phenotype (methane emissions, rumen size and morphology, digesta flow rate) in detail 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 host control of methane production in sheep is multi-dimensional, so phenotyping sheep involves measurement of the rate of digesta flow, rumen volume, transcriptome, proteome of the rumen wall and microbial metagenome. We have complete phenotypes for these traits from the sheep in this project and have identified some genes expressed in the rumen wall that appear to be linked to methane production. There are also some unique molecular features with important roles in regulating rumen development and metabolic processes that may also be influencing the microbial community in the rumen (microbiome).

The associations between these host genes and methane emissions are being explored from sheep flocks in New Zealand and Australia. The final analysis to try and bring together all of the phenotypic, genotypic, transcriptomic and the ruminal microbial genome is now underway and we are confident that we will identify some of the key targets for improving our genetic selection and management of animals to be more efficient.

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

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

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

Collaborating organisations: [1]UWA; [2]Murdoch University, [3] DPI Victoria, [4]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% to 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 their 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.

Our mission is to use antimethanogenic pasture legumes and novel grazing systems to reduce methane emissions from sheep by at least 20% while maintaining or improving sheep productivity. *In vitro* studies have shown that there is large variation in methane production between different legume species and between cultivars within the same species. In these studies, biserrula consistently reduced methane yield compared to other mainstream pasture species grown across southern Australia.

The research team sought to determine whether the *in vitro* findings would be repeated *in vivo* when sheep were fed pastures freshly cut from the UWA Shenton Park Facility. We tested annual ryegrass, bladder clover, subterranean clover, serradella and biserrula. Our two major findings were that: (i) biserulla reduced methane on the basis of daily volume, dry matter intake and energy intake; and (ii) the ranking of methanogenic potential among plant species between *in vitro* and *in vivo* was the same.

The two grazing experiments that we have completed at the UWA Future Farm, Ridgefield in Pingelly indicate that it is much more difficult to demonstrate reductions in methane emission intensity in the field. There is evidence that including legumes in the grazing mix and providing them as a choice can improve productivity, but the variability associated with the methane measurements make it difficult to determine if there is a flow on effect on emissions intensity.

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

Plot scale grazing experiment at UWA Farm Ridgefield. Subclover left and biserrula right.

Investigating Indonesian forages for their potential to reduce methane emissions whilst increasing productivity in local ruminants

Project team: Amriana Hifizah[1] (PhD Candidate; amriana.hifizah@research.uwa.edu.au); Prof Philip Vercoe[1]; Prof Graeme Martin[1]; Prof Muhammad Hambal[2]; Dr Reza Ferasyi[2]

Collaborating organisations: [1]UWA; [2]Faculty of Veterinary, University of Syiah Kuala, Aceh, Indonesia

Methane (CH_4) emitted by ruminant livestock is an important contributor to global warming. Importantly, CH_4 emissions are an energetic loss to the animal so prevention of emissions will also increase production efficiency. For these reasons, there is great interest in forages that will reduce methane emissions.

Both aspects of the CH_4 problem, the greenhouse gas emissions and the energy inefficiency, are directly relevant to Indonesia, a developing country with a rapidly increasing demand for ruminant products such as meat and milk. Thus, ruminant livestock will continue to be a prominent source of food, as well as many other resources (traction, investment) so ways to mitigate their environmental impact need to be found.

The aims of this projects were to collect information about plants in Aceh that could be used to feed local ruminants. This information will be used to rank plants for their potential as forage for local goats and cattle. Up to 50 species will then be selected for the next stage of the project.

Quantitative *in vitro* procedures to compare the traditional and alternative forages for 'fermentability' in the rumen (total gas production), methane production and rumen microbial populations will be used. Initially, batch culture will be used to screen the alternative forages. This will be followed by continuous culture in an artificial rumen (the RUSITEC) to reduce the list of candidates for further analysis (ideally < 5).

The nutritional value of the best candidate alternative forage(s) in rations formulated for the local goats, using measures such as liveweight gain, and the major characteristics of rumen function will be determined.

Ultimately, we expect to be able to suggest a mix of novel forages and traditional high-value forages in a balanced diet that provides optimal intake energy and protein whilst significantly decreasing methane emissions. The idea is to reduce greenhouse gas emissions whilst maintaining, and perhaps even improving, productivity.

This research is supported by LPDP (Indonesia Endowment Fund for Education) and UWA.

International coordination of the Ruminant Pangenome Project

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

Collaborating organisations: [1]UWA; [2]NSW-DPI; [3]CSIRO; [4]Murdoch University; [5]University of New England; [6]Ternes Agriculture Company; EU Framework 7 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 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. It will provide high quality data and new knowledge that will be used to deliver a comprehensive understanding of the animal genotype–rumen environment–management interactions that drive methane emissions from livestock. This knowledge will shape future strategies for reducing emissions and will therefore underpin the development of methodologies under the Carbon Farming Initiative.

The broader RPP project has the specific research objective of developing a better understanding about: (i) host control of methane emissions from sheep; (ii) genetics to reduce methane emissions from Australian sheep; (iii) the trade-offs between feed-use efficiency, methane and reproduction in sheep; and (iv) maximising energy-yielding rumen pathways in response to methane inhibition.

The international coordination of the RPP has progressed well during 2015. A highlight has been the interaction with the METHAGENE project, which is a project funded through the European Cooperation in Science and Technology (COST) program. The METHAGENE team are attempting to look at how best to harmonise the protocols that are being used to collect methane emission data from individual ruminant animals and combine datasets so that the information can be used more effectively in genetic selection programmes to reduce methane emissions.

We have also been engaged with the Global Research Alliance on Agricultural Greenhouse Gases program and with the Animal Selection, Genetics and Genomics Network to contribute to the global effort to reduce emissions from livestock. We have been involved in the planning of the International Conference, Greenhouse Gas and Animal Agriculture that will be held in Melbourne in 2016. The Rumen Pangenome Project will sponsor one of the plenary sessions at the conference and be involved in satellite workshops.

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

Do feed legumes affect reproductive hormone production in livestock?

Project team: Assoc/Prof Hiroya Kadokawa[1] (leader; hiroya@yamaguchi-u.ac.jp); Prof Graeme Martin[2]; Hackett Prof Kadambot Siddique[2]; Dr Stacey Rietema[2]; Dr Kiran Pandey[1]

Collaborating organisations: [1]Joint Faculty of Veterinary Medicine, Yamaguchi University, Japan; [2]UWA

Multiple births in beef cattle are rare, limiting the productivity of beef production systems. Producers of high-value breeds, such as the wagyu breed Japanese Black cattle, are searching for strategies to increase the occurrence of twins. In sheep, short-term feeding of legumes such as lupins and cowpea to livestock is known to increase lamb production, by increasing ovulation rate. A similar strategy may prove effective in beef cattle.

The improvement in fertility and fecundity in sheep induced by feeding legumes is commonly thought to be in response to the high nutritive value of legumes. However, it is also possible that legumes improve fertility because chemical compounds in the legumes affect the activity of reproductive hormone activity.

Japanese Black cow and calf. Photo: Hiroya Kadokawa.

This study aimed to test whether chemicals capable of disrupting reproductive hormone activity in sheep and cattle exist in two legumes, lupin (*Lupinus angustifolius*) and cowpea (*Vigna unguiculata*).

Pituitary and ovary cells were collected from female sheep and Japanese Black cattle immediately after slaughter at an abattoir. The cells were grown, and extracts from lupin and cowpea were added to the cell culture, to determine whether they affected the hormone production of the cells. Preliminary data suggests that lupin contains substances which inhibit the production and activity of oestrogen, an important female reproductive hormone.

Therefore, feeding lupins may improve lamb production by altering the activity of oestrogen in the ewe. Furthermore, feeding lupins to Japanese Black cattle may be a strategy to improve productivity in this breed by increasing the occurrence of twins.

This research is funded by the Japanese Ministry of Agriculture, Forestry and Fisheries.

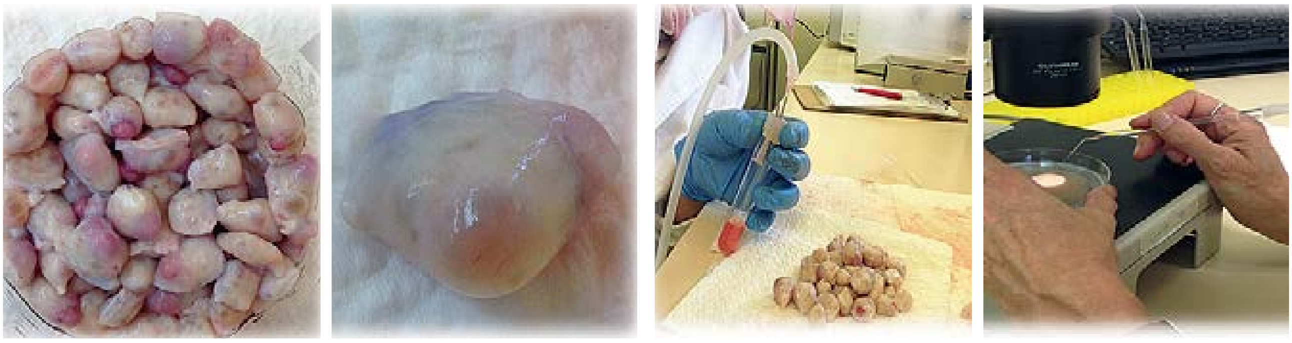
Effect of isoflavones on the maturation of sheep oocytes *in vitro*

Project team: Ms Anna Aryani Amir[1] (PhD Candidate; anna.amir@research.uwa.edu.au); Prof Graeme Martin[1]; Dr Zoey Durmic[1]; Dr Dominique Blache[1]; Dr Jennifer Kelly[2]; Dr David Kleemann[2]

Collaborating organisations: [1]UWA; [2]South Australian Research and Development Institute (SARDI) Turretfield Research Centre, South Australia

Phytoestrogens are oestrogen-like but non-steroidal substances that are classified according to their chemical structure, with one prominent class being the isoflavones. The serious problems caused by phytoestrogens in clovers on fertility in female sheep are well documented and led to the inclusion of 'duty of care' in the development of novel pasture species.

With a view to assessing new forages promoted for anti-methanogenic properties, whether or not isoflavones (genistein, biochanin-A, formononetin) affect the maturation and developmental competence of sheep eggs *in vitro* have been tested. Cumulus-oocyte-complexes from abattoir-sourced adult ovaries were allocated for the treatments, fertilized and cultured *in vitro*. Cleavage of the



Oocyte collection and ***in vitro*** maturation.

eggs (a sign of fertilization) and embryo development rates were recorded.

No significant effects at the lower concentrations (2.5-10 µg/ml) of any isoflavone on any measure of embryo development were found. However, for all three isoflavones, the high concentration (25 µg/ml) caused significant effects: genistein decreased cleavage rate (92% vs 80%), blastocyst rate (62% vs 45%) and blastocyst efficiency (57% vs 36%); biochanin-A decreased cleavage rate (92% vs 57%) and blastocyst efficiency; (57% vs 32%) formononetin decreased blastocyst rate (62% vs 45%) and blastocyst efficiency (57% vs 42%).

These outcomes in vitro suggest that isoflavones from fodder could cause reproductive failure in vivo. Further investigation is needed with a focus on early morphogenesis and trophectoderm nuclei of the embryos.

This research is supported by Institute of Tropical Agriculture, Universiti Putra Malaysia and UWA.

Brain Regulation of Reproduction: Challenging the 'KNDy' Hypothesis

Project team: Prof Graeme Martin[1] (PhD Candidate; graeme.martin@uwa.edu.au); Dr Jeremy Smith[1]; Dr Penny Hawken[1]; Dr Stacey Rietema[1]; Professor Michael Lehman[2];

Collaborating organisations: [1]UWA; [2]University of Mississippi Medical Center

The brain switches reproduction on and off by changing the frequency of pulses with which it releases 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'.

If the KNDy hypothesis is to persist, it needs to be able to explain acute changes in GnRH pulse frequency, such as that evoked by nutritional signals or by pheromones.

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.

This research is supported by ARC Discovery Grant.

Does selection for temperament in sheep affect the control of the stress hormone cortisol?

Project team: Dr Stacey Rietema (leader; stacey.rietema@uwa.edu.au); Assoc/Prof Dominique Blache; Professor Graeme Martin; Dr Penny Hawken

Selection for a low responsive, or 'calm', temperament is seen as a tool to improve the animal welfare, ease of handling, and productivity of livestock. A calm temperament in sheep, cattle, and poultry is linked to smaller hormonal responses to stressors, particularly of cortisol, an important hormone for controlling other processes in the body, including growth, reproduction and immune function, during stress.

This study tests whether selection for temperament in sheep affects cortisol concentrations, and therefore affects the activity of other hormones. In the first experiment we tested whether temperament affects the daily pattern of cortisol release in the absence of stressors, and whether this led to any changes in the daily pattern of the release of another stress hormone, prolactin, and the metabolic hormones leptin and insulin.

The results showed that temperament did not affect the daily pattern of cortisol, prolactin, or leptin concentrations. However, animals with a calm temperament had higher concentrations of insulin in the early

Sheep undergoing testing for temperament. Photo: Dominique Blache.

afternoon than those with a more responsive, or 'nervous', temperament. In a second experiment, whether or not temperament affects whether sheep exposed to multiple stressors develop symptoms of mild chronic stress was tested. After exposing animals to 15 different stressors over three weeks, neither calm nor nervous animals seemed to develop any evidence of chronic stress in cortisol or insulin concentrations, nor in their response to an acute stressor. Nervous animals had a bigger cortisol response to the acute stressor than calm animals, regardless of exposure to the previous 15 stressors.

Therefore, although selection for temperament in sheep affects the behavioural and cortisol response to an acute stressor, it does not affect the resting activity of cortisol nor the tendency to develop mild chronic stress. Temperament does appear to affect insulin activity, but this is not because of changes in the concentration of cortisol.

This research is funded by UWA.

Genetics of breeding for breech strike resistance

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

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

Global wool production, specifically that by 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) and it results in a substantial annual loss to the industry. Skin wrinkles located in the breech area (surrounding the anus) are a major predisposing factor: about 90% of flystrike occurs in this area. Breech flystrike is currently controlled by application of insecticides to the sheep, or by shearing, crutching and mulesing. Mulesing is a surgical procedure that was developed in 1940 and involves removal of skin from the breech. While it remains the most efficient control for flystrike and cannot yet be matched by alternative control methods, it has come under increased scrutiny during the last decade as public awareness of animal production systems has increased. All of the current methods are also costly, so alternatives are needed.

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 that could be used to select indirectly for breech strike resistance.

Chemical odours that attract or repel the flies (*Lucilia cuprina*), known as 'semiochemicals', are showing great promise as an area of research. Wool sourced from the breech area on animals from a genetic resource flock is being used to characterise them for their ability to attract, repel and/or kill the flies that cause flystrike. The aim is to identify those semiochemicals that may play a significant role in resistance or susceptibility to breech strike, and

Odours and fly strike.

to estimate the heritability of the bioactive semiochemicals so we can determine whether it would be feasible to use them to breed for flystrike resistance.

In 2015 we refined our protocol for testing the behaviour of *Lucilia cuprina* so that we could obtain more accurate measures of the choice they make in response to wool that has been sampled from sheep that have been bred to be resistant or susceptible sheep. There are some clear tweaks that have to be made to study Lucilia cuprina and we are now much better placed to prepare them for the electroantennogram studies we have planned. The electroantennogram studies enable us to pass compounds across the antennae of the flies to identify which compounds stimulate a response. We'll use this to guide us towards the identification of compounds that are most likely candidates for influencing whether the flies are attracted or repelled to the different types of wool.

At this stage the most common odours contributing to flystrike appear to be in the form of alkanes, phenols and benzene rings, but some unknown chemicals also appear to play a role.

This research is funded by AWI.

Determining the importance of a nest to laying Pekin ducks

Project Team: Ms Lorelle Barrett (leader; lorelle.barrett@research.uwa.edu.au); Assoc/Prof Dominique Blache; Prof Shane Maloney

Global production of duck meat is increasing, with the Australian industry following the international growth trend. One issue that may limit continued increases in productivity is that of floor-laying, a behaviour where eggs are laid on the floor and not in the nest boxes provided to the breeding females. This behaviour is not well understood in domesticated ducks and it is unclear whether floor laying ducks suffer poorer welfare than nest-laying ducks.

This project uses the behavioural demand method, preference testing and physiological responses to determine the level of motivation for ducks to seek a nest site. The results of these experiments will help identify important factors of nest-use by Pekin ducks and develop recommendations to improve both production and welfare outcomes for the industry.

Using the original behavioural demand method for ducks, developed at UWA, the motivation of female ducks to lay eggs in the nest box used by commercial producers was tested. The preferences of female ducks for different nesting site substrates, such as sawdust and AstroTurf, and their motivation to access their preferred substrate to lay eggs was also tested.

In addition to their motivation, the birds' behaviour was recorded and the levels of stress hormone in the egg and the changes in body temperature were measured. These parameters will be used to assess the level of stress in individual birds when they are not able to access the preferred substrate.

All data are now collected and are currently being processed and analysed. Results thus far indicate that ducks have a preference for sawdust as nest material, and that most of the female ducks are strongly motivated to use a nest box.

This research is funded by Poultry CRC and RSPCA Australia.

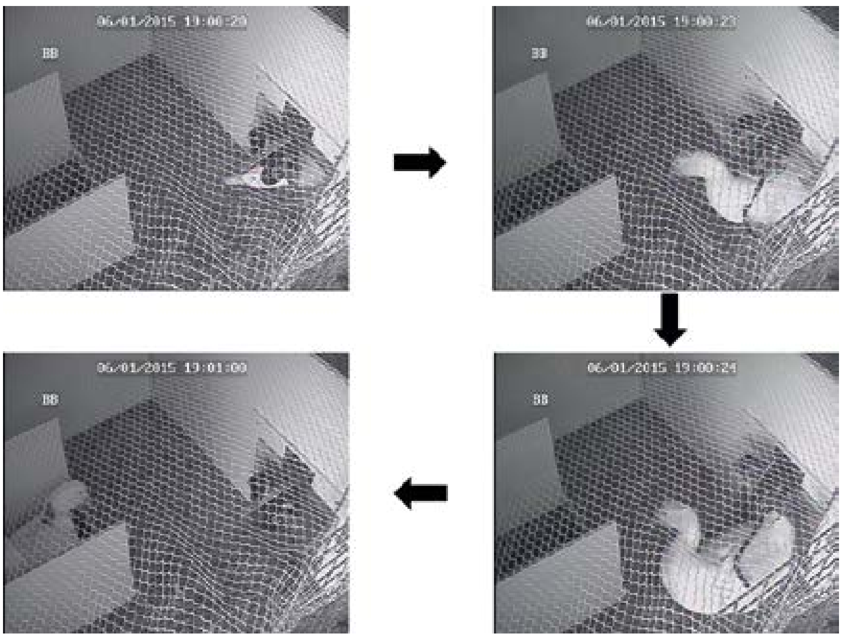


Photo sequence of a female Pekin duck using the behavioural demand apparatus to access her nest.

Young male alpacas.

Pain management during castration in Alpacas

Project team: Assoc/Prof Dominique Blache[1] (dominique.blache@uwa.edu.au); Prof Shane Maloney[1]; Dr Amin Mugera[1]

Collaborating organisations: [1]UWA; [2]Australian Alpaca Association

In the animal industry, castration is a valuable management tool but it is also a source of concern from an animal welfare perspective. The existing standards for castration, or the new standards developed for other livestock species, cannot be applied to alpacas because of the specific morphological and developmental characteristics of the alpaca. In 2015 a project to test different methods of castration and pain management in alpacas was run.

A large online survey to explore knowledge, practices and needs of stakeholders was conducted. The 259 participants who completed the survey were commercial alpaca producers (54%), alpaca hobby farmers (32%), veterinarians (11%) and representatives of animal protection organisations (APOs; 3%). The national distribution was representative of that of the industry.

The outcomes of the survey were analysed and a summary was sent to a panel of 20 stakeholders (producers, veterinarians and APOs). Phone interviews with four veterinarians, four producers, and two representatives of APOs were conducted. The survey results and the discussions with the panel of experts have indicated that the following should be tested: 1) surgical castration with the different combination of long acting painkiller (oral or injectable Meloxicam) and sedation and local analgesic or Trisolfen and 2) rubber ring with or without oral Meloxicam.

An unexpected outcome was that the impact of testis size rather than age should be also included in the trial. The criteria for the methods of castration identified were animal welfare, cost and efficiency. The parameters to be measured were behavioural (feeding, posture, walking, etc) and physiological (endorphin, cortisol) markers of pain and discomfort.

The effectiveness of each procedure will be assessed by measuring the increase in plasma cortisol. The cost will be estimated using an economic evaluation based on data collected during the experiment and further discussion with veterinarians. The final design of the animal experimentation was further discussed with Dr Jane Vaughan and other members of Australian Alpacas Association before obtaining the approval from the UWA Animal Ethics Committee. The animal experimentations will be conducted in 2016.

This research is funded by the Rural Industries Research and Development Corporation (RIRDC)

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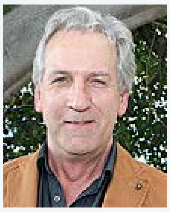
Water for Food Production

Theme Leaders:



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The increase in global population is occurring at a time when the area of land under agricultural production throughout the world has reached a static point at about 37% of total land area. About 20% of agricultural land is irrigated but this provides 40% of the world's food and can give crop yields that are 2-4 times greater than rainfed agriculture.

Meeting the food needs of an increasing world population will require improved efficiencies in irrigated agriculture and better use of finite water resources. The challenge is to produce more food with less water, while preserving environmental integrity.

About 70% of freshwater withdrawals around the world are used for agriculture and the most common technique is flood irrigation, even though conveyance losses can exceed 20% and plants only use about half the water that is actually applied. Inefficient irrigation systems that supply too much water without adequate drainage can also lead to salinization and soil structure decline which can reduce crop yields by 10 to 25%. In arid and semi-arid areas salinization may already be affecting up to 50% of the irrigated area. There is also an increasing awareness of the negative environmental impacts of poorly managed irrigation systems.

Locally, the State Government's Water and Natural Resource Management Initiative (agric.wa.gov.au/n/2301) overseas investment of over $50 million directly into building capacity and efficiencies in providing irrigated agriculture for local and international markets. Perhaps the single largest investment is the Gascoyne Food Bowl initiative (agric.wa.gov.au/n/1825), in the far northwest of Australia. This program will release 400 ha land and infrastructure for horticulture development, with a further 800 ha identified for future expansion.

The development of such irrigation schemes requires water 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 will be underpinned by teaching (undergraduate units, Masters and PhD) and research components: economics, plant water use, agronomy, irrigation design and sustainable water management systems. There will be a strong focus on industry collaboration and engagement, water balance and irrigation modelling, environmental sensing and assessment, postgraduate training and technology exchange.

Studying impact of water allocation strategies on the horticulture sector in Western Australia: equity and efficiency considerations

Project team: Mr Sayed Iftekhar (leader; mdsayed.iftekhar@uwa.edu.au), Assoc/Prof James Fogarty

Collaborating organisations: [1]UWA; [2]Department of Water; [3]vegetablesWA

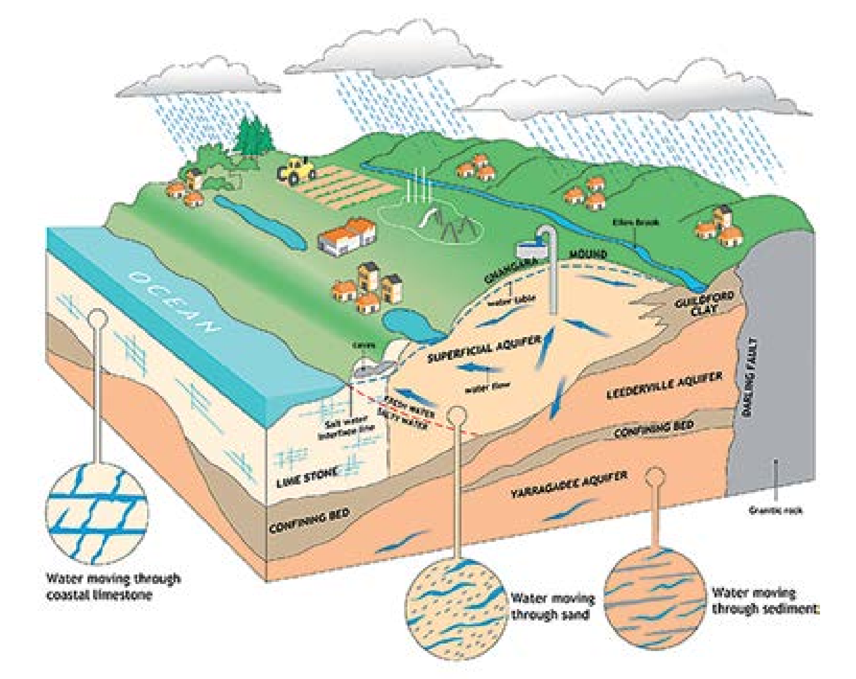
In many parts of the world groundwater is depleting at an alarming rate, and water regulation authorities are facing the challenge of reducing groundwater extraction by existing users. However, to take appropriate adaptation measures it is necessary to understand the distributional consequences of groundwater depletion.

In water resource management, the issue of the equity-efficiency trade-off has been explored in a number of different areas, but not in the context of water allocation reductions from a groundwater system. To contribute to this knowledge gap, an empirical case study for the Gnangara Groundwater System (GGS) of Western Australia was conducted.

The water level in this system is depleting at a consistent rate for various reasons including, increasing demand and climate change. The Department of Water is currently considering reducing the allocation to existing licence holders.

A combination of scenarios were tested using an individual-based farm optimisation model parameterised with the individual licence-specific data on area and water allocation. Farms with larger areas or more initial water allocation were found to be likely to lose more revenue per unit of water reduction. As a consequence, an efficiency argument would dictate reduction of water from farms that already have low water allocation per hectare but the equity argument would suggest the opposite. These results reveal the complexity in setting up an appropriate allocation reduction strategy.

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



Gnangara groundwater system diagram. Photo: Department of Water

Effectively Utilising Water Allocations for Managing Turfgrass in Open Spaces

Project team: Dr Louise Barton (leader; louise.barton@uwa.edu.au), Prof Tim Colmer, Mr Sam Flottmann

Southern Australia is expected to experience a significant decrease in water resources due to changing climate. Turfgrass managers are under continued pressure to restrict water use, while also maintaining high quality surfaces. The importance of maintaining sports turfgrass so as to encourage physical activity is well recognised within the community, however there is increasing evidence that well designed and maintained green spaces are also needed for mental health and well-being.

Water allocation is a key water planning method being utilised for irrigating public open spaces in southern Australia. Understanding how to best manage turfgrass on current, and possible lower future water allocations, is critical for managing these community areas.

The overall objective of our field-based project is to investigate approaches to best manage current and possible future water allocations to turfgrass in public open spaces. Consequently, the project is investigating if turfgrass can be maintained with a water allocation (7500 kL ha-1 year-1), and the implications of further lowering the allocation on turfgrass quality; evaluating how an annual water allocation is best distributed during the year; and assessing if using a wetting agent can improve the effectiveness of a water allocation.

The third year and final year of field assessment was completed in 2015. The research demonstrated turfgrass can be maintained on the current water allocation if it does not experience excessive wear. Lowering the water allocation will have a negative impact on turfgrass quality, although this may be partially mitigated by using an effective wetting agent. Furthermore, simple approaches utilising historical climate data can be used to effectively distribute an annual water allocation during the irrigation season. Key findings were presented to stakeholders at and Industry Seminar Day, free workshop and via the distribution of factsheet.

This research is supported by Horticulture Innovations Australia Limited (HIA) in partnership with the Local Government and members of the Australian Turf Industry.

International Water Centre's Master in Integrated Water Management

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

In 2015 nine students visited UWA for the Water and Agricultural Landscapes module of the International Water Centre's (IWC) Master in Integrated Water Management.

The Water and Agricultural Landscapes module was first developed through the Centre for Ecohydrology by UWA Professors Neil Coles, Susana Neto and Jeff Camkin in 2012. It is delivered annually and is based on a seven-day intensive and reflective learning experience at UWA with field trips to Gnangara and the Peel-Harvey region.

Prior to travelling to Perth, each participant provided details about their background, education and professional experience, personal learning objectives from the module and the Master of Integrated Water Management (MIWM), career aspirations and a case study they would follow throughout the module to support their learning process.

The week was packed with a succession of lectures, workshops and field trips. Participants were following lectures presented by highly regarded academics and practitioners in the water and agricultural landscapes, including Hackett Prof Kadambot Siddique, Hackett Professor of Agriculture Chair and Director, Institute of Agriculture; John Ruprecht, Director of Irrigation at the Department of Agriculture and Food; A/Prof Ed Barrett-Lennard, Principal Research Fellow, School of Plant Biology; and Simon Skevington, Project Director of Western Australian Government's multi-agency Water for Food Program at the Department of Water.

The intensive but highly enjoyable week culminated in student presentations of the main learnings, sources of inspiration and how they intend to use their learnings in their future careers.

For more information on the International Water Centre's Master of Integrated Water Management visit www.watercentre.org.

Turfgrass managers discuss wetting agents to improve soil water content at a workshop at UWA.

Development and Testing of Sensor Systems to Aid Agricultural Water Management.

Project team: Prof Keith Smettem, Dr Mark Rivers, Prof Ed Barrett-Lennard, Prof Nick Harris (Southampton University), Dr Julian Klaus (Luxembourg Institute of Science and Technology).

Collaborating organisations: [1]UWA; [2]Southampton University; [3]Luxembourg Institute of Science and Technology

Irrigation with brackish and recycled water is increasing worldwide. One of the challenges is to sense when chemical concentrations in the rootzone become detrimental for plant growth and adjust irrigation to flush the system if such conditions are encountered. This project has developed and is currently testing low cost chloride sensors for salinity management in irrigation systems and is actively exploring development of new chemical sensors for a range of monitoring applications.

The work is presently supported by the Fonds National de la Recherche (FNR), Luxembourg as part of a larger project aimed at evaluating chemical movement in the Environment.

International Water Centre's Masters' students look at lettuce crops on a field trip in Western Australia

Linked to this project is a PhD study on efficient treatment of wastewater using vertical flow wetlands conducted by Iraqi Government Scholar Ms Rasha Al-Saedi. This project aims to design efficient wastewater treatment systems capable of yielding water suitable for irrigation of high value tree crops and public recreation areas.

This research is supported by the Fonds National de la Recherche (FNR), Luxembourg and the Iraqi Government Scholarship.

Increasing wheat yield during drought in rainfed environments

Project team: Mr Araz Abdullah (MSc Candidate; araz.abdullah@research.uwa.edu.au), Hackett Prof Kadambot Siddique

Collaborating organisations: [1]UWA; [2]ACIAR; [3]ICARDA

In Mediterranean-type environments, grain yield is limited by the amount of water available for transpiration especially during the grain filling period.

In 2015, the effectiveness of film-forming antitranspirants as a method of reducing water loss, and ultimately increase yield was investigated. Antitranspirants are emulsions of wax or latex that reduce water loss through transpiration by forming a thin film on foliage.

The research showed that by applying the film-forming antitranspirants during booting, the most drought-sensitive stage in wheat development, the adverse effects of late-season drought on wheat growth and yield were alleviated.

Two experiments were conducted in a temperature-controlled glasshouse at UWA to compare well-watered and water deficit watering treatments, with antitranspirants sprayed before booting, before flowering was complete, or not at all.

Grain yield was improved in drought-stressed plants where the antitranspirants had been applied prior to the boot stage.

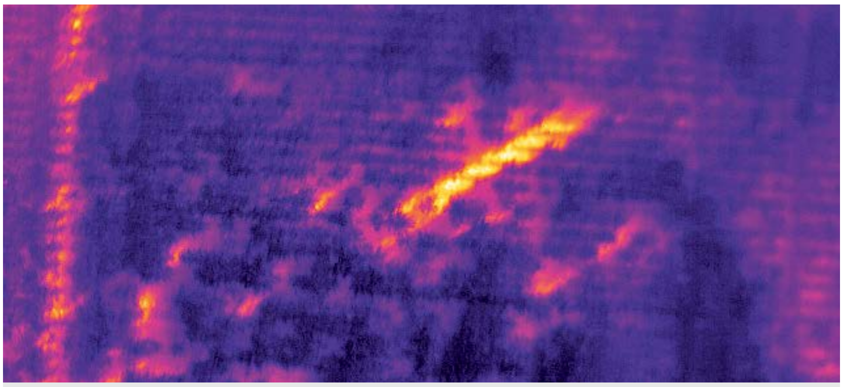
Other research in the area suggests that the application of film-forming antitranspirants could restrict photosynthesis and limit growth, but the research findings from this study showed that reducing water loss during booting in wheat development outweighed any photosynthetic limitations.

Antitranspirant application may have a significant positive impact on crop yields and priority should be given to testing the wider applicability of these results, especially under field conditions in rainfed environments. The findings may enable farmers in climates where late-season drought occurs frequently, to increase wheat yield.

The findings from this research were published in a paper entitled "Film antitranspirants increase yield in drought stressed wheat plants by maintaining high grain number" in Agricultural Water Management.

The research is a part of the Mr Araz Abdullah's Master of Science studies supported by the Australian Centre for International Agricultural Research (ACIAR) in collaboration with UWA and the International Centre for Agricultural Research in the Dry Areas (ICARDA).

This research was supported by ACIAR and ICARDA.



Thermal image of wheat plants under various growth and stress conditions collected from a Remotely Piloted Aircraft System (RPAS) or drone.

4

Food Quality and Human Health

Theme Leaders:

Professor Jonathan Hodgson

Dr Michael Considine

Development of healthier foods and food ingredients can make a positive contribution to both the Australian economy and human health. The development and validation of healthy foods that meet consumer desires is an exciting challenge for the Australian agri-food industries.

To satisfy this growing need, we must train the next generation of scientists and industry champions and provide guiding knowledge on policy development for the Australian academic and industry bodies.

Health attributes of foods is an important driver for food choices. Consumption of healthy foods is the cornerstone of efforts to improve diet quality in populations. We know that a higher intake of plant foods is associated with lower risk of chronic diseases.

In particular diet quality has a major impact on the development and progression, and prevention and treatment of chronic diseases and disorders. Although diet is linked with health of all organ systems such as bones, kidneys, lungs and brain, it is most closely linked with cardiovascular diseases and their related disorders. Specific dietary changes have the potential to reduce the incidence of cardiovascular diseases by more than 30%.

Knowledge in this area provides the opportunity to work with plant food industries to 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 University of Western Australia has strengths in this area. Also critical for achieving desired outcomes is development of cross-faculty collaboration, collaboration with other researchers from within Western Australia as well as outside Western Australia, and collaboration with relevant industries and their representative bodies. Thus integrating the complementary skills, knowledge and activities across disciplines and organisations will result in increased success.

This research is leading towards the development of a 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.

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

Project team: Dr Michael Considine[1] (leader; michael.considine@uwa.edu.au), Prof Jonathan Hodgson[1], Prof Kevin Croft[1], Dr Catherine Bondonno[1], Prof Wallace Cowling[1], Dr Matthew Nelson[1], Prof Tim Mazzarol[1], Dr Elena Mamouni Limnios[1], Prof Geoff Soutar[1], Dr Fucheng Shan[2], Dr Kevin Seaton[2]

Collaborating organisations: [1]UWA; [2]DAFWA; PomeWest

The global 'functional foods' market exceeds $10 billion. It's widely known that fresh fruits and vegetables provide a range of dietary health benefits, and inadequate consumption is a major cause of morbidity. Yet, the fresh fruit and vegetable industries have a very limited ability to capture a share of the functional foods market.

This project seeks to bridge the gaps in knowledge to capture the healthy values of Australian-bred apples which are richer in flavonoid antioxidants. The project spans several disciplines and several activities. Principal achievements in 2015 were developing and publishing a website aimed to educate and promote the healthy properties of apples, and opportunity to breed healthier apples. See http://tinyurl.com/breeding-healthier-apples. Two other major activities in progress are to develop a pedigree map that relates genetic fingerprints to the flavonoid content of germplasm from the Australian National Apple Breeding Program and to determine the consumer attitudes and perceived value of a theoretical flavonoid-rich apple.

Due to the extended and multidiscipline nature of this project, a variation has been requested, to extend the project for 12 months.

This research is supported by Horticulture Innovation Australia (AP12036), partnered by DAFWA.

The DAFWA Bravo™ apple was used as the prototype for consumer preference testing.

Flow-mediated dilatation in action. This is one of a number of measures used in the project team to establish the cardiovascular benefits of eating flavonoid-rich apples.

Lupin-containing foods for improved human health

Project team: Prof Jonathan Hodgson[1] (leader; jonathan.hodgson@uwa.edu.au), Prof Trevor Mori[1], Dr Natalie Ward[2], Assoc/Prof Stuart Johnson[2], Prof Lawrie Beilin[1], Assoc/Prof Seng Khee Gan[1], Dr Carolyn Williams[3], Mr John Ashton[4], Mr Todd Kuehlmann[5]

Collaborating organisations: [1]UWA; [2]Curtin University; [3]Centre for Entrepreneurial Innovation; [4]Sanitarium; [5]Il Granino Bakery

Cardiovascular disease (CVD) is the number one cause of death world-wide, killing over 17 million annually. In Australia, close to one third of all deaths are due to CVD, which has an estimated annual cost to the health budget of ~$8bn and total economic cost of ~$15bn.

Increasing the intake of fruits, vegetables and whole grains remains the foundation of dietary approaches to prevent CVD. This alone has the potential to cut CVD risk and associated costs by up to 30%.

Ongoing programs of research involve development and evaluation of lupin-containing foods. These foods have the potential to benefit both Australian agriculture and population health.

Lupin, a grain legume, is particularly rich in protein and fibre and contains negligible carbohydrate. Lupin-derived food ingredients such as lupin flour can be substituted for refined carbohydrate (usually from wheat) resulting in increased protein and fibre and reduced carbohydrate content of the food.

Studies at UWA have shown that this can result in reduced appetite, improved blood sugar metabolism and lower blood pressure. Results of this research has identified prevention and management of type 2 diabetes and associated risk of CVD as the principal future research focus.

Ongoing studies will establish whether regular consumption of lupin-containing foods can improve blood sugar management, insulin sensitivity and measures of vascular health in type 2 diabetic individuals.

This research is supported by the Royal Perth Hospital Medical Research Foundation.

Lupin flakes can be used in a variety of dishes to reduce carbohydrate content of the food, and increase protein and fibre content.

Genomic research to improve the value of the Narrow-leafed lupin (*Lupinus angustifolius* L.) grain.

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

Collaborating organisations: [1]UWA, [2]CSIRO Agriculture, Murdoch University

Narrow-leafed lupin (NLL) is a major grain legume crop in Australia that has recently been gaining recognition as a human health food. The grain is high in protein and dietary fibre, whilst low in fat and starch. Certain undesirable traits however must be addressed in order to increase the value of the grain compared to the leading market competitor, soybean.

This research focuses on the accumulation of quinolizidine alkaloids (QAs) in the grain - toxic secondary metabolites which must remain below the Australian food and feed standard of 0.02%. Mechanisms of alkaloid biosynthesis, transport and responses of these to environmental conditions are poorly understood, with grain levels often exceeding this threshold. This project uses a genomic approach to identify and characterise genes involved in the biosynthesis and transport of QAs, serving to assist breeding efforts in producing NLL grain that consistently meets industry requirements.

In 2015, expression profiles of QA biosynthesis genes were investigated in tissue types of lupin species. Highest expression levels were found in high vs. low QA producing species, and also in stem and leaf compared to root, flower and developing seed tissues. These results are consistent with previous literature finding that QAs are synthesised mostly in green tissues.

Quinolizidine alkaloid research in Narrow-leafed lupin (*Lupinus angustifolius* L.) varieties.

In addition, the project is making progress to identify the low-alkaloid gene iucundus using bioinformatic and molecular approaches. This gene has been incorporated into all modern NLL cultivars, but its function is unknown. Identification of this gene will give a greater understanding in the regulation and biosynthesis of QAs.

The impacts of drought and increased temperature on the production of QAs were also investigated; these environmental conditions coincide with pod-filling in the south-west Australian agricultural region. Results were however not as expected, with a decrease (as opposed to increase) in leaf QA gene expression under these stressed conditions. Grain QA content under these conditions is yet to be determined in order to assess whether this reduced leaf expression results in reduced total grain QA content.

In order to perform this analysis, a method is currently being developed in collaboration with Murdoch University's Separation Science and Metabolomics Laboratory for the detection and measurement of QAs in lupin tissues. We also aim to implement this method for future QA experiments.

This research is supported by the GRDC, CSIRO Agriculture and a UWA University Postgraduate Award (UPA).

Improved varieties of maize is adopted by rural households in Timor-Leste.

Improved food crop varieties in Timor-Leste

Project team: Prof William Erskine (leader; william.erskine@uwa.edu.au)

Collaborating organisations: [1]UWA; [2]ACIAR; [3]DFAT; [4]Timor-Leste Ministry of Agriculture and Fisheries

The Seeds of Life (SoL) program in Timor-Leste aims to improve food security in rural areas by raising the productivity of the nation's staple food crops.

SoL has a long term approach to agricultural development and targets the introduction of improved crops to more than fifty percent of all cropping farmers in Timor-Leste before the end of 2016.

SoL commenced its life as an ACIAR project immediately after the population of Timor-Leste voted for independence during the UN-led referendum in 2000. Since then the program has progressed through various phases of research and development. The current phase (SoL3) is supported by the Australian Government through the Australian Centre for International Research (ACIAR) and the Department of Foreign Affairs and Trade (DFAT) in collaboration with the Timor-Leste Ministry of Agriculture and Fisheries (MAF). The program has a total budget of $27.5 million, of which $25 million is managed by UWA.

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%. All released varieties were selected after being cultivated under farmer conditions over a number of years and passing through a rigid consumer evaluation system. The array of available improved food crop varieties continues to expand with plans to release new varieties of mung beans and red beans.

The focus is now on developing the national seed system to ensure widespread dissemination of the new highly promising varieties. The adoption research in Timor-Leste indicated that the likelihood of an individual adopting a new variety is strongly related to the closeness of social relationships with growers already using that variety. So as the SoL program expands its activities across all Timor-Leste Districts during 2014, more than 1,000 community seed production groups were being supported directly by SoL and 500 others by NGOs. These seed production groups build on previously-existing farmer groups, piggy-backing on existing social relations among farmers. This is then leveraged for successful seed dissemination in the new seed production groups. Thirty five of the groups have developed into large Farmers Associations, all of whom are developing the capacity to sell their own labelled seed.

In 2013 the adoption rate of MAF released varieties was by 25% of all rural households in the country. By 2014 this adoption rate had risen to 33% and early results indicate that in excess of 50% of rural households have adopted one or more of the MAF-released varieties.

The success of the program is being measured in improvements not only to food security but also in the capacity of the MAF to continue support the seed system in the future. The program has supported five MAF staff with MSc studies in the last two years: two in Indonesia (one male, one female), and three at UWA (one male, two female).

This research is supported by ACIAR, and DFAT in collaboration with the Timor-Leste Ministry of Agriculture and Fisheries.

5

Agribusiness Ecosystems

Theme Leaders:

Dr Amin Mugera
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W/Prof Tim Mazzarol
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Agribusiness encompasses all the various businesses that lie between on-farm production and the point of consumption. These include farming, seed supply, agrichemicals, farm machinery, wholesale and distribution, processing, marketing, and retail sales.

The agribusiness industry is substantial and comprises around 135,447 agricultural businesses operating across Australia. Despite a decline of around 3.5% in the number of agricultural enterprises in Australia over the past 15 years, there has been a substantial increase in the productivity of those that remain. For example, Australia's farms have increased the amount of arable land by around 31%, while the gross value of agriculture has risen by around 34%.

The Agribusiness Ecosystems theme focusses on addressing issues related to the governance of the agribusiness firms along the food value chain with a focus on changing consumer behaviour due to changes in dietary and consumption patterns, adoption of new innovations, production and financial risk management, farm productivity and profitability, global food security and nutrition, commodity marketing, new venture creation and governance structure of co-operative enterprises.

It will also examine the behaviour of agribusiness ecosystems using an framework and will seek to map the structure, growth, performance and health of selected agribusiness ecosystems 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 are will be involved in theme. 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.

The aim is to build a robust model of the agribusiness ecosystem that can be applied to regional, national and global contexts and be used to develop in-depth understanding of how to facilitate these systems.

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 partnering 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 2014 and 2015 National Mutual Economy reports led to a Federal Senate enquiry into the contributions of Co-operative and Mutual Enterprises to the Australian economy. As a result $14 million federal funding was committed in July 2015 to the industry.

A discussion paper, Australia's Leading Co-operative and Mutual Enterprises 2015 was prepared by the UWA Co-operative Enterprise Research Unit and published in 2015.

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

Retaining stubble is predicted to reduce emissions relative to burning it near Dalwallinu, Western Australia. Photo: Elizabeth Meier

Achieving least cost greenhouse gas abatement: opportunities in Australian grain farms

Project team: Dr Peter Thorburn[2] (leader; peter.thorburn@csiro.au), Dr Marit Kragt[1], Ms Nikki Dumbrell[1], Dr Elizabeth Meier[2], Mr Jody Biggs[2]

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

Agricultural soils are a source of greenhouse gas emissions. Fortunately, changes in practices can decrease agricultural greenhouse gas emissions, and even reduce atmospheric greenhouse gas concentrations by re-sequestering carbon in soils or vegetation. The potential for Australian grains farms to sequester carbon in their soils and/or reduce nitrous oxide emissions may not be achieved because practices that maximise soil carbon or reduce nitrous oxide emissions may either reduce farm profitability or fit poorly within the overall farm management.

The objectives of this project are to estimate the net, whole-farm greenhouse gas mitigation potential of a range of farm management scenarios (e.g. retaining stubble, increased cropping intensity, modified nitrogen fertiliser rates) in current and future climates; and estimate the whole-farm financial effects of these management scenarios to mitigate greenhouse gas emissions.

Modelling has been conducted to predict the trade-offs between yield, greenhouse gas reductions and farm profitability under different management for case study farms across the major grain growing regions of Australia. Case study farms have been set-up to be representative of farming conditions and current farm management at: Chinchilla (Queensland); Brigalow (Queensland); Dalwallinu (Western Australia); Kellerberrin (Western Australia); Wimmera (Victoria); and Southern Mallee (Victoria).

The preliminary results indicate that it is possible to reduce greenhouse gas emissions on Australian grain farms by adopting practices that increase soil carbon and/or reduce soil nitrous oxide emissions. Additionally, the results also indicate that net emissions reductions are a trade-off between increases in soil carbon stocks and reductions in nitrous oxide emissions, especially for farms in the warmer and wetter climates (e.g. Chinchilla and Brigalow).

Readily adopted changes to farm practices (e.g. retaining stubble or reducing over-fertilisation with nitrogen) can reduce net greenhouse gas emissions without, in some cases, reducing farm profitability. However, to achieve the greatest predicted emissions reductions more substantial farm management changes were required (e.g. summer cropping in Western Australia and Victoria), which tended to decrease farm operating profits.

Work is ongoing to estimate the greenhouse gas mitigation potential of management changes under future climate conditions and under mixed grain-livestock farming systems. Work is also continuing to establish the relative profitability of the farm management changes under different price conditions.

This research is supported by the Australian Government's Department of Agriculture and Water Resources and the GRDC.

Climate change in Western Australian broadacre agriculture: a bioeconomic and policy analysis

Project team: Mr Tas Thamo[1] (PhD Candidate; tas.thamo@uwa.edu.au), Prof David Pannell[1], Dr Marit Kragt[1], Dr Maksym Polyakov, Dr Louise Bartion[1], Dr Ross Kingwell[2], Dr Michael Robertson[3], Dr Dean Thomas[3], Mr John Young[4], Dr Wahidul Biswas[5], Ms Deborah Engelbrecht[5]

Collaborating organisations: [1]UWA; [2]AEGIC; [3]CSIRO; [4]Farming Systems Analysis Service; [5]Curtin University

Western Australia's grainbelt is one of Australia's major agricultural regions. However, the region's climate is experiencing a warming and drying trend that is projected to continue. In recent debates about climate policy in Australia there has been much interest in and enthusiasm about using agriculture for mitigating climate change, based on a belief that sequestration of carbon in soil and reforestation of farmland could provide cost-effective abatement.

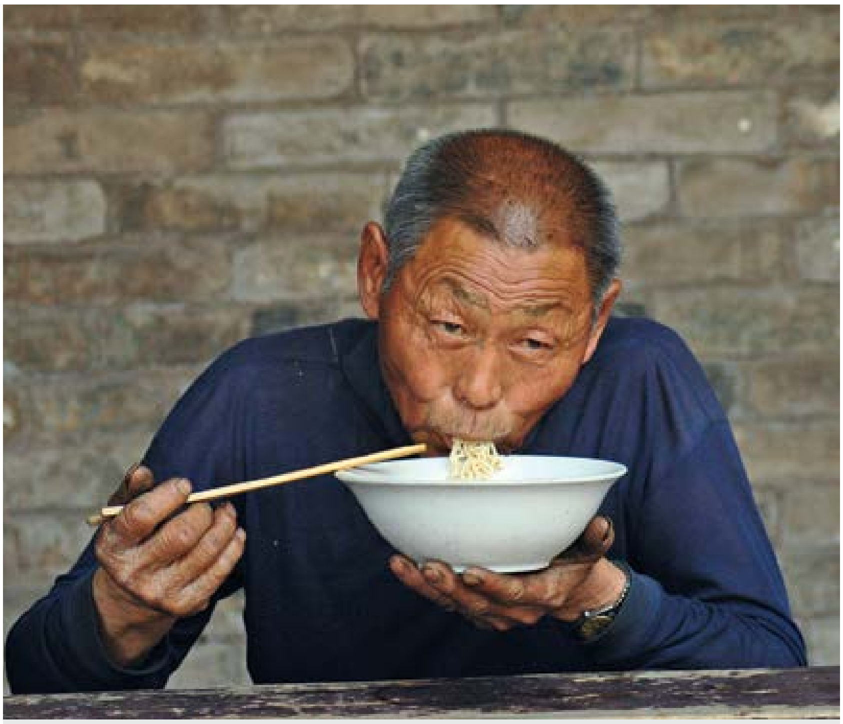
The aim of this research was to investigate the possible bioeconomic impacts of future changes in climate, and the likely cost-effectiveness of policies to mitigate climate change in the agricultural sector, in the WA grainbelt.

Biophysical models were used to simulate firstly the impact of different climate scenarios on crop yields, pasture and tree growth, and secondly, the impact of different land management practices on carbon sequestration. The results of these simulations were then incorporated into a bio-economic optimisation model of a mixed cropping-livestock farming-system for further analysis. Even though in the future the impacts and policy aspects of climate change are likely to be simultaneously relevant to farm businesses, joint consideration of both is a unique approach taken in this research.

Across a range of climate scenarios, the impact on farm profit varied between -103% to +56% of current profitability in 2030, and -181% to +76% for 2050. In the majority of scenarios profitability decreased. If the warming/drying trend predicted for the region translates into either large temperature increases and/or rainfall reductions, then results predict substantial reductions in agricultural profitability. Adaptive changes to management under severe climate scenarios included reductions in crop inputs and animal numbers and, to a lesser extent, land-use change. Whilst the benefits of this adaptation were substantial (the financial impact of climate change was 15% to 35% greater without it), profit reductions were still large under adverse climate scenarios. Compared to profit margins, production (e.g. crop yield) was much less sensitive to climate change. The means that relatively minor increases in yields or prices would be sufficient to maintain profitability. However, if these price and/or productivity increases would have occurred regardless of climate change, then the actual cost of climate change may still be high.

The potential for agricultural land in the grainbelt to act as a low-cost carbon sink seems limited, particularly for soil carbon. To incentivise large-scale land-use change to sequester carbon would appear to require a relatively high carbon price (higher than featured in contemporary political discussions). Compounding this, from a policy perspective, the characteristics of sequestration make it inherently difficult to cost-effectively deploy as a mitigation option. Even where agriculture profitability was substantially reduced under the impact of climate change, the financial attractiveness of reforesting farmland did not necessarily increase, because climate change also reduced tree growth, and therefore the income from sequestration. Although agriculture is a larger emitter of greenhouse gases, for a typical central grainbelt farm, a carbon price on these emissions has less effect on profit than (moderate) climate scenarios.

This research is supported by the GRDC and Future Farm Industries CRC.



The traditional Chinese diet is changing with a growing middle class.

China's changing diet and its impact on greenhouse gas emissions

Project team: Mr Jacob Hawkins (PhD Candidate; jacob.hawkins@uwa.edu.au), Assoc/Prof Chunbo Ma, Assoc/Prof Steven Schilizzi, Asst/Prof Fan Zhang

With China's increasing wealth over the last 30 years, its diet has shifted to include more carbon intense foods such as fresh fruit, fresh vegetables, meat, and dairy products. As China has grown economically, it has opened itself to the global marketplace and is among the top importers of foods. In this time, China has become the world's top producer of greenhouse gas emissions and the changes in its food consumption play a substantial role in this, not only from its own domestic food production, but also from the embodied emissions in foods China imports from its trade partners. Until now, it has been unclear how the changes in China's diet have affected greenhouse gas emissions, both for itself as well as for the nations supplying food to China. This project aims to quantify the greenhouse gases associated with China's changing diet and explore the drivers behind increases in food-related greenhouse gases.

A review of the body of literature using environmentally-extended input-output analysis to evaluate environmental issues in China was published in 2015, *Promises and pitfalls in environmentally extended input-output analysis for China: a survey of the literature*. This review illustrates the explosion of the use of technique with regard to issues in China and the many ways the field has advanced, but the problems of questionable data veracity and lack of disaggregated data indicate that using input-output analysis for this research would be troublesome, if not infeasible.

Findings on the increase in greenhouse gas emissions associated with China's increased consumption of livestock products were presented at the 2015 Australian Agriculture and Resource Economics Society national conference in Rotorua, New Zealand in February. Further, a presentation on the utilisation of existing Food and Agriculture Organization data to derive implied carbon emission factors for food products was given for the Go8-C9 PhD Forum on Graduate Perspectives from China and Australia: Big Data in Nanjing, China in November.

The research was also highlighted in media coverage on the ABC Science Show in December with the airing of the story, *Emissions jump with dietary changes in China*.

This research is supported by Australian Postgraduate Awards (APA).

Dynamics of profitability and productivity in the farm sector

Project team: Dr Amin Mugera[1] (leader; amin.mugera@uwa.edu.au), Asst/Prof Andrew Ojede[2], Prof Michael Langemeier[3]

Collaborating organisations: [1]UWA; [2]Texas State University; [3]Purdue University

This research project sought to find the main sources of farm level profitability and productivity, by farm size and specialisation, in US agriculture. A rich dataset of 256 farms in Kansas over an 18 year period from 1993 to 2010 was used to investigate and understand how farm profitability and productivity has been changing.

The analysis was based on recent advances in index numbers and mathematical programming methods where profitability change is decomposed into changes in total factor productivity (TFP) and terms of trade (TT). The nonparametric data envelopment analysis method is used to further decompose TFP into technical change and different measures of output-oriented efficiency change. Statistical methods were also used to investigate the dynamic relationship between different components of productivity on farm profitability.

Only a few of the farms studied were able to adopt new innovations. Photo: Fishhawk

The results indicated that profitability change is mainly driven by productivity change and the main source of productivity change in is technological innovation. Only a few farms were able to uptake new innovations and therefore most farms end up lagging behind the best performing farms.

The results have important implication on the funding model for US agriculture. The results also point to the need for prudent appropriation of both state and Federal research funds to research institutions in the forefront of agricultural innovations for the long-term survival and growth of the US farm sector. These results were recently published in the *American Journal of Agricultural Economics*.

Vulnerability to poverty in developing countries

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

Extreme poverty remains a big challenge in developing countries and is on top of the agenda for the Suitable Development of the United Nations Development Group. There is a consensus among development practitioners and policy makers that ending poverty in all its forms needs to look beyond current poverty status and should also be concerned about vulnerable to poverty, the likelihood the individuals who are not poor can be pushed to become poor in the near future.

Master's candidate Denis Abagna completed his thesis titled Poverty and Vulnerability to Poverty in Ghana: An Empirical Analysis. This study assessed poverty and vulnerability to poverty and its determinants in Ghana using the 2005-2006 Living Standards Survey. Analysis is based on the Foster-Greer-Thorbecke (FGT) and Vulnerability as Expected Poverty frameworks. The results indicate higher vulnerability to poverty rates than prevailing poverty rates across different administrative regions. Urban households, male-headed households, and single-headed households were found to be more vulnerable. Household size, dependency ratio and age of household head are vulnerability increasing, while agricultural income, asset ownership, remittance and formal education are vulnerability reducing. The results have policy implication in designing of poverty alleviation programs.

PhD candidate Masood Azeem

Young farm workers in Ghana. Photo: Sicrump completed a study titled Poverty and vulnerability in Punjab, Pakistan: A multilevel analysis. This study estimated the prevalence and extent of vulnerability to poverty in the Punjab province of Pakistan. A multilevel model was used to analyse survey data of about 90,000 households distributed across 150 towns/tehsils. Empirical estimates show that the vulnerability rate is higher than the rate of poverty, and poverty-induced vulnerability is higher than risk-induced vulnerability. Moreover, idiosyncratic-vulnerability is higher than covariate-vulnerability. Unlike previous studies that find poverty to be a rural phenomenon, this research shows that poverty and vulnerability are equally high in urban areas. A high level of urban vulnerability adds urgency to anti-poverty interventions given a rapid urbanisation in Pakistan.

Results from this study are now published Journal of Asian Economics.

Sisters tend to the family's crops in Malawi. Photo: Jeannie O'Brien/Trocaire

Shadow pricing farmland environmental services: the case of legume-based cropping systems and symbiotic nitrogen

Project team: Assoc/Prof Atakelty Hailu[1] (leader; atakelty.hailu@uwa.edu.au), Mr Robertson Khataza[1], Dr Marit Kragt[1], Prof Graeme Doole[2]

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

As a response to low crop productivity and concerns over the environment, sustainable agricultural intensification practices such as legume-based conservation agriculture are re-gaining prominence in Sub-Saharan Africa and across the globe.

In this study, the shadow price of symbiotic nitrogen as a factor of production was determined, and the technical efficiency for legume-based cropping systems (LBCS) in Malawi was estimated. Survey data collected from a sample of 135 plots, representing the integrated maize-legume cropping systems was used.

By addressing the above objectives, the research will make two scholarly contributions. First, the study will estimate the economic value of symbiotic nitrogen as a factor of production. Currently, empirical evidence is sparse on the economic value of LBCS' nutrient-recycling role. Thus, valuing the benefits of biological nitrogen derived from symbiotic nitrogen can help ascertain the economic importance of LBCS, and justify the role of legumes in conservation agriculture and sustainable environmental management.

Second, the study will estimate the level of technical (in) efficiency, and suggest policy alternatives that can improve farm productivity and food security situation among smallholder farmers in Malawi.

This research is supported by the Australian Government's Department of Foreign Affairs and Trade Australia Awards in Africa.

Food security in sub-Saharan Africa

Project team: Dr Amin Mugera[1] (leader; amin.mugera@uwa.edu.au), Dr James Fogarty[1], Ms Rose Aawulenaa[1], Ms Laurine Kithi[1]

Collaborating organisations: [1]UWA; [2]Australia Africa University Networks

Ensuring food security remains a critical challenge for governments in sub-Saharan Africa. From a broad perspective food insecurity is not just a result of insufficient food production, availability, and intake; it also encompass poor quality or nutritional value of the food and unsustainable production practices that contribute to low food production. Gender disparity in household headships is a contributing factor to food insecurity and child malnutrition in Africa.

Laurine Kithi completed a Master thesis titled "Impacts of Farmer Field Schools on Food Security and Environmental Conservation in Western Kenya." This study assessed the impacts of Farmer Field Schools (FFS) on household food security and environmental conservation in Western Province of Kenya. The outcome variables are: maize yield per acre, income per acre, household food insecurity score and environmental conservation score. Principal component analysis and propensity score matching techniques were used for analysis and regression method was used to test the robustness of matching results.

The results indicate significant differences in yields and income per acre between FFS households and non-FFS households; FFS households have higher yields and income per acre than their counterparts. The study also shows that FFS program reduces severity of food insecurity but has no significant effect on environmental conservation. This implies that FFS plays a critical role in enhancing household food security.

Rose Aawulenaa completed her Master thesis titled "Effect of Gender of Head of Household on Food Security and Child Nutrition in Northern Ghana." The study investigated whether the gender of the head of a household is a determinant of food security and child nutritional status in northern Ghana. The results show that there are differences in the food security and child nutritional status of female-headed households (FHHs) and male-headed households (MHHs). Based on the observed characteristics, FHHs are found to be less food secure, and their children nutritionally deficient although the prevalence of these nutrition deficiencies varies among households. Even after taking into account the observed differences across FMMs and MHHs, the food security and child nutritional status of FHHs is not found to be better than those of their MHHs counterfactual. The implication of the study is that policy interventions that support education for both FHHs and MHHs are relevant for improving the food security and nutritional status of children.

Shrimp Value Chains in Indonesia

Project team: Dr Amin Mugera[1] (leader; amin.mugera@uwa.edu.au), Dr James Fogarty[1], Ms Maharani Yulisti[1]

Collaborating organisations: [1]UWA; [2]Texas State University

International trade of seafood is big business, with most trade following from the South to the Northern countries. Access to Northern countries' markets is influenced by food safety and certification standards. Indonesia is a major exporter of shrimp to the US and Japan.

PhD candidate Maharani Yulisti aims to investigate the emerging governance structure of the shrimp industry in Indonesia and understand how this structure influences the implementation of food safety standards (FSS).

The study will analyse the impacts of adoption of FSS on the welfare of smallholder and investigate the determinants of smallholder producers' choice of marketing channels.

The specific objectives of the study are to analyse the governance structures of food safety standards implementation on shrimp value chain in Indonesia, and to investigate the key determinants of food safety standards implementation in shrimp farming and its impacts on producer welfare as measured by farm profit, production yield, and sales. How implementation of food safety standards influence the choice of marketing channel for smallholder shrimp farmers in Indonesia will also be investigated.

It is expected that the results from this study will help formulate policies that can improve the welfare of producers.

For the qualitative study, a case study research design will be used to collect data from representatives from government agencies, fish processing plants, traders or exporters, industry associations and NGOs. Data will be collected using in-depth interviews with key informants.

The quantitative study will be based on farm household data collected using a survey. Recruitment of households to interview will be random in each selected village that

Shrimp Value Chains in Indonesia.

will be purposively chosen as having a good representation of producers who are either implementing food safety standards or not. Human Ethics approval to conduct the data has been granted and all logistics are in place to commence the field work.

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

Risk-coping strategies of poor rural households in Vietnam

Project team: Asst/Prof Benedict White (leader; benedict.white@uwa.edu.au), Ms Giang Nguyen

This research project aims at identifying how poor rural households in Vietnam cope with income shocks. Using a balanced panel data of 1915 households in two provinces in Vietnam from 2006 to 2012 we analyse how different shocks, either covariate or idiosyncratic, affect households' welfare and their consequent responses.

The framework of consumption smoothing theory was applied to evaluate how well households insure their consumption against floods, animal diseases, crop diseases and health shocks. The results showed that households successfully insure their consumption against the idiosyncratic shock of illness but not against the large covariate shock of floods, which is in accordance with Complete Market Hypothesis. However, the results also showed evidence that households would rather reduce their consumption to invest more in productive assets in the case of crop diseases. This is in accordance with recent empirical works testing Asset Smoothing Theory. While animal diseases appear to be over-compensated as well as increase output price, they had no impact on consumption. Households use public transfers and credit to invest in productive assets, and use private transfer to insure against health shocks

Harvesting rice in Vietnam.

and animal diseases. However, when floods happen, all of these risk-sharing networks are undermined.

To further understand the responses, the allocation of labour hours of each households was analysed and categorised into their three major allocations: agriculture, wage and small businesses. Agricultural households were the most and in several cases the only affected allocation when shocks happen. In accordance with the recent literature on labour supply to shocks, a significant increase in labour allocation to wage activities when floods happen was noted. However, the re-allocation is significant only after two years of the shocks. In the year when shocks happen, agricultural households tended to increase agricultural labour time rather than wage-related activities. Further interaction with locations showed distinct differences due to characteristics of local terrains and economy.

The results were presented at Australia Economists Conference in Brisbane in 2015.

This research is supported by the Australian Government's Department of Foreign Affairs and Trade Australia Awards.

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Education and Outreach Activities

Effective communication of research outcomes and training opportunities to farmer groups, industry, collaborators, funding bodies and potential students is a core strategy for IOA. Equally, IOA has a role in listening to growers, advisors and agribusiness, to ensure their ideas and perspectives are considered in the identification of key issues and opportunities.

IOA uses a number of communication channels to achieve its objectives of increasing the rate of uptake of the University's agricultural research, and to enhance UWA's identity and reputation for high quality agricultural research.

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 to an audience of farmers, academics, scientists and representatives from industry and government.

Demonstrating the multi-disciplinary nature of agriculture, seven students from the Schools of Animal Biology, Plant Biology, Earth and Environment, Agricultural and Resource Economics, and The UWA Business School presented their research in 2015, the ninth consecutive event.

UWA's Vice Chancellor Professor Paul Johnson gave the opening address, and the two sessions were chaired by members of IOA's Industry Advisory Board, Dr Michael Robertson, CSIRO and Mr Richard Williams, CBH Group.

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

Ms Lyndie Bayne	The spread of environmental sustainability practices in the Western Australian agrifood sector
Mrs Chandima Ranawana	The role of transpiration in ameliorating leaf temperature in wheat in relation to changing environmental conditions
Ms Xiaoyan Qiu	Gene polymorphisms associated with temperament in Merino sheep
Ms Joginder Gill	Phosphorus dynamics in soil supplemented with burnt crop residues
Mr Bede Mickan	Interactions involving *Arbuscular mycorrhizal* fungi under soil water deficit
Mr Adam Jalaludin	Nature mimics science: double EPSPS mutation in *Eleusine indica*
Mr Tas Thamo	Climate change impacts, mitigation policy and their interaction in West Australian mixed crop-livestock farming

IOA Industry Forum

Where are we headed with the red meat industry?

IOA's annual Industry Forum held at the University Club of Western Australia in July 2015 posed the question 'Where are we heading with the red meat industry?'

The event, now in its ninth consecutive year was attended by approximately 200 guests and focussed particularly on the sheep and cattle industries, and what Australia needs to do to maintain its competitive export market.

Meat and Livestock Australia's (MLA) managing director Mr Richard Norton delivered the opening address on how MLA is building demand of red meat and Mr Robert Davidson, WAMMCO discussed how it is growing it export markets. Cattle and sheep farmers Mr Paul O'Meehan and Mr Robert Egerton-Warburton presented a case-study of running family-operated businesses. The final speaker for the day was research economist Professor Garry Griffith from the University of New England. The talks were summed up by IOA Industry Advisory Board member Mr Shane Sander who also led the panel discussion.

For the full program and access to presentations, see ioa.uwa.edu.au/publications/industry-forum

Deputy Vice-Chancellor (Community and Engagement) Prof Kent Anderson delivers the Industry Forum opening address to a full house.

Dowerin Field Days

IOA connected with farmers, the agriculture industry, students and the rural community at the Dowerin Field Days 2015 in August. The two-day event is one of the biggest agricultural shows in the country hosting 22,000 exhibitors and attendees.

IOA's booth formed part of the Department of Agriculture and Food's (DAFWA) display, which was themed Careers in Agriculture this year. Forming part of the display were PhD students Mary-Anne Lowe and Abdulkareem Alsih from IOA and the School of Earth and Environment's research into non-wetting soils.

Visitors to IOA

In 2015, IOA further strengthened its research links and collaborations with institutions and industry in Australia and overseas through hosting more than 20 national and international visitors.

The visitors included scientists from partner organisations, industry stakeholders and government representatives.

Among them were students from French agricultural universities, and researchers from Zhejiang University, Lanzhou University and Chinese Academy of Agricultural Science in China.

For further information, see ioa.uwa.edu.au/publications/newsletters

Ms Mary-Anne Lowe shows a budding young scientists some rocks found on UWA Farm Ridgefield at the Dowerin Field Days.

Mr Jianyong Wang (centre) from Lanzhou University visited Adjunct Prof Neil Turner (left) and Hackett Prof Kadambot Siddique for 12 months from May 2015.

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 April, 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, provides an overview of the Institute's vision and mission and is the first point of contact for people searching for information on activities in agriculture and related areas within the University.

Upcoming events are publicised on the IOA homepage along with a repository of the latest media statements distributed. Documents such as the IOA Strategic Plan, annual research reports and newsletters can also be found on the website.

In 2015, IOA extended its online presence to social media with a Twitter account @IOA_UWA. Twitter is a service that allows a user to stay connected with its followers through the exchange of messages no greater than 140 characters of text. The tweets can include photos and videos. Throughout 2015, IOA's Twitter presence grew to 155 followers.

Public Lectures

In 2015, IOA hosted two public lectures:

Date	Presenter	Organisation	Title
15 March 2015	Professor David Hopkins	The Royal Agriculture University, England, UK	Hector and Andrew Stewart Memorial Lecture: Soils and the ends of the Earth, and a few places in between
5 June 2015	Dr Hermann Stuebler	Bayer CropScience	Bayer CropScience chemical and genetic technologies to help global agriculture feed a growing world

Media Statements

IOA continued communicating the University's agricultural research outcomes to the general public through the media by distributing 31 media statements throughout 2015. A substantial amount of media coverage was generated in local, rural, national and international print, broadcast and online media.

Date	Title
15 January 2015	Short-term debt enhances WA farm productivity
2 February 2015	UWA soil scientists honoured for challenging ideas
5 February 2015	Hot-spot summer school unites young climate experts
6 February 2015	Oats to clean up heavy metals in contaminated soil
20 February 2015	Renowned soil scientist to give Hector and Andrew Stewart Memorial Lecture
9 March 2015	How does wheat respond to climate change
14 April 2015	The farmer takes a drone
21 April 2015	A century of spectacular wheat yield improvements in China
22 April 2015	Swan Valley honey fest is bees knees
6 May 2015	Positive outlook for WA's farming system groups
8 May 2015	Sunflower protein 'scissors' provide sunny news for medicine
15 May 2015	China-Australia Joint Research Centre established
29 May 2015	Forrest Research Foundation Scholarships attract world's best minds
1 June 2015	Growing crops in salty soils gets easier one step at a time
5 June 2015	Harnessing social capital can boost crop production
9 June 2015	Small changes have large benefits for crop breeding
23 June 2015	Where are we heading with Australia's red meat industry
30 July 2015	Nitrogen loss in soils unearthed
31 August 2015	Field Day to showcase UWA's commitment to agriculture and rural communities
2 September 2015	Arctic study finds CO2 helps plants grow but only at low temperatures
14 September 2015	Agricultural practices unknowingly cause poisoning of lake catchement
22 September 2015	Australia can move from 'mining boom' to 'dining boom'
23 September 2015	Student enrolments in agricultural science major double at UWA
29 September 2015	UWA students shine at Australian crops competition
30 September 2015	Antarctic warming stimulates diversity of soil fungi
2 October 2015	UWA researcher addresses the United Nations to end hunger
6 November 2015	Local researchers take on G20 challenge to make energy efficient wheat
11 November 2015	Smart agriculture students explore ways to increase wheat yield
26 November 2015	UWA helping in the East African fight against crop devastating plagues
7 December 2015	Mali looks to WA to develop its meat and livestock industry
9 December 2015	WA agricultural research shines on world stage

Prof Phil Vercoe with Pingelly farmer Garry Page discuss the benefits of including native based pastures on farms.

Outreach and teaching activities at UWA Farm Ridgefield

The highlight of outreach and teaching activities at UWA Farm Ridgefield was the bi-annual field day, held in September 2015. This year's theme was Managing Risk: Climate, Mental Health, Sustainability.

Farmers and local community members came together to interact with UWA researchers and students to learn more about UWA Farm Ridgefield and the Future Farm 2050 Project. The Field Day had formal presentations on Crop Yield Risk, Issues in Rural Health and FarmSafe Western Australia and a visit to demonstration sites 'Multi-Species Native Based Pasture' and the 'Avon River Catchment Critical Zone Observatory'.

At the Field Day the federally funded program 20 Million Trees Project was also launched in partnership with Greening Australia. Through this program, the FF2050 Project and Greening Australia will plant 100 ha of non-arable land with permanent vegetation (including 100 ha of direct seeding and seedlings (or 80000 trees). These new farm management practices will improve both the productivity and conservation values on the farm.

In February 2015, Ridgefield hosted the Critical Zone Observatory Summer School. Twenty students from seven countries and nine universities went to Ridgefield to share their global perspectives on responses to climate change and in particular looked at landscape and soil-related climate change issues.

In 2015, approximately 100 undergraduate students used Ridgefield for field work as part of the units Land Use and Management (EART3338), Clean, Green and Ethical Animal Production (ANIM3306) and Avon Catchment (ENVT4406). The field work enabled students to get field experience in their chosen area of study. In addition, approximately 15 post-graduate students used Ridgefield for their field work as part of the Sustainable Grazing Systems unit (AGRI14408).

Student volunteers contributed to planting 3,600 native trees and shrubs at Ridgefield in 2015. The trees were planted as part of the FF2050 Project to rehabilitate non-arable areas to create a mix of mosaic and corridors that will eventually link the few remnants of native bush and extend to neighbouring farms, public roadside verges and nearby nature reserves. Student volunteers also completed a tree audit of previous years' plantings to record the number of trees that had established and identify management requirements in planted areas. The tree plantings were supported by UWA Facilities Management as part of their carbon offset commitment.

UWA Farm Ridgefield hosted four interns from high-level French agricultural colleges (AgroParisTech, Montpellier Supagro, Ecole Nationale Superieure Agronomique Toulouse, Agrocampus Ouest) for approximately seven months from September 2015 March 2016. The international students gained hands-on agricultural experience while contributing to the successful completion of harvest and other farm activities.

Two Master of Social Work (School of Population Health) students undertook a 13-week placement with the FF2050 Project with a focus on Community Development and building relationships with Pingelly community members. In addition, six Masters students undertook the Cross-Faculty Wheatbelt Project with a focus on UWA Farm Ridgefield and Pingelly. Students were from the School of Arts, School of Business, School of Engineering and School of Earth and Environment. The students developed a report with suggested opportunities for development for Ridgefield and Pingelly.

Towards an Understanding of Rural Communities

Project team: Dr Susan Bailey[1] (leader; susan.bailey@uwa.edu.au), Dr Susan Young[1]

Collaborating organisations: UWA[1]; Pingelly Community Resource Centre; Pingelly Aboriginal Progress Association; Shire of Pingelly; Beverley Community Resource Centre; Shire of Beverley

The Community Resource Centre Network

Over the last four years UWA staff and students studying a Master of Social Work and Social Policy have engaged with, and worked alongside community members in Pingelly and Beverley to document strengths and identify ideas for community development projects.

The aims of this project are to develop strong relationships with rural communities, to build an understanding of strengths and needs of rural communities in the West Australian grain belt, and to identify opportunities for community development projects. Strong rural communities is a key pillar of the Future Farm 2050 Project on UWA Farm Ridgefield.

In 2015 UWA students and community met to share ideas in Beverley and compiled a Beverley Community Profile Book. A Pingelly Next Step group was formed to develop a concept plan for the redevelopment of the Pingelly Hospital.

This research is supported by the Pingelly Community Resource Centre and the Shire of Pingelly.

Are we going against the grain in training? Developing an adult education framework for the farming community

Project team: Ms Dominie Wright[1] (leader; dominie.wright@research.uwa.edu.au), E/Prof Lynette Abbott[1]; Dr Natasha Pauli[1]; Dr Bill MacLeod[2]; Prof Nancy Longnecker[3]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]University of Otago

The project has continued to evaluate the data collected in 2014 from two surveys on the training needs of growers and agronomists in the Australian grains industry. A visit to Wageningen University in The Netherlands was used to strengthen the educational aspects of the research in collaboration with their Education and Competency Group.

Social Work and Social Policy staff and students help develop strong rural communities.

Farm Field tour with AIAEE April 2015. Tour group of delegates are examining a solar powered weed picker invented by the owner of this organic farm

In 2015 a Youtube Channel "Training Growers" to help extend knowledge of pest and diseases in crops to growers and agronomists within the grains industry was developed. In conjunction with the videos, webinars were held on topics that were impacting on crops, for example powdery mildew of wheat, rust in barley, sclerotinia in canola.

During the growing season in 2015 (June to September) ten videos to explain the symptoms of the disease or pests on the crop, their impact on yield and how to manage the pest or diseases in crops were developed. The videos attracted 700 views during the four months.

Agronomists, who could not attend the webinar, were able to watch the video and refer back to it when needed. The feedback has been very positive and the process will be repeated in 2016. The topics for the webinars are selected from PestFax and advertised through the PestFax networks directly to those interested. eXtension Aus have also used the videos by placing either a link to the Youtube channel or embedded the video onto their website. Further information about the usefulness of the videos to growers and agronomists was collected at field days in northern wheatbelt of Western Australia.

This research is funded by the Council of Grain Growers Organisation (COGGO) and GRDC Grains Industry Research Scholarship.

Memoranda of Understanding

Letter of MOU extension between UWA and Kerala Agricultural University, India	January 2015
Letter of MOU extension between PMDS-Arid Agriculture University Rawalpindi, Pakistan	March 2015
China-Australia Joint Research Centre for Ruminant Production, North-West Agriculture and Forestry University, Yangling, China	May 2015
International Academic Agreement signed between UWA and ESALQ, University of Sao Paulo, Brazil	June 2015
Letter of MOU extension between UWA and Gansu Academy of Agricultural Sciences, China	September 2015
Agreement for Academic Cooperation between UWA IOA and The United Graduate School of Veterinary Science, Yamaguchi University, Japan	October 2015
MOU between UWA and International Center for Agricultural Research in the Dry Areas (ICARDA)	October 2015
International Sponsor Agreement between UWA and The University of Agriculture, Faisalabad, Pakistan	November 2015
MOU between UWA and Segou University, Mali	December 2015
MOU between UWA and Regional Polytechnic Institute of Katibougou, Mali	December 2015

Awards and industry recognition for staff in 2015

NAME	AWARD
E/Prof Lyn Abbott	Joan Eveline Award for Mentoring, presented at the 20th Anniversary of the UWA Leadership Development for Women Program
Dr Olivier van Aken	The Vice-Chancellor's Mid-Career Research Award
Mr Benjamin Congdon	Best Student Presentation at the Australiasian Plant Pathology Student Symposium
Prof Wallace Cowling	31st Elmer Heyne Crop Science Lectureship, Kansas State University, Kansas, USA
Adj/Assoc/Prof Muhammad Farooq	COMSTECH Award 2015 for Excellence in Science and Technology – 'Young Scientist Award'
Adj/Assoc/Prof Muhammad Farooq	Top cited paper award from the University of Agriculture, Faisalabad, Pakistan
Dr Matthew Hipsey	The Vice-Chancellor's Mid-Career Research Award
Ms Eviness Nyalugwe	Underwood PhD Scholarship
Prof David Pannell	The Vice-Chancellor's Award in Research Mentorship
Prof Stephen Powles	Sectional Committee – Agriculture, Veterinary Science and Applied Biology of the Australian Academy of Science
Dr Yichao Rui	Excellent Presentation Award at 3rd International Symposium on Sustainable Agriculture for Subtropical Regions, Changsha, China
Hackett Prof Kadambot Siddique	Foreign Fellow of National Academy of Agricultural Sciences, India
Hackett Prof Kadambot Siddique	International Fellow of the Indian Society of Plant Physiology
Hackett Prof Kadambot Siddique	30th Qi Zhen Global Lecture, Zhejiang, China
Prof Ian Small	Fellow of the Australian Academy of Science
Adj/Prof Hari D Upadhyaya	Dr Harbhajan Singh Memorial Award for contributions to Plant Genetic Resources by the Indian Society of Plant Genetic Resources.

New Research Projects 2015

Title	Funding Period	Funding body	Supervisors
Evaluation of Musa acuminata subsp. malaccensis for resistance to Fusarium wilt of banana'	2015	UWA UQ Bilateral Research Collaboration Award	Prof Jacqueline Batley, Assoc/ Prof Elizabeth Aitken
Establishing the extent and significance of viruses with wind-borne insect vectors arriving from nearby countries and establishing in northern Australia	2015-2017	CRC for Plant Biosecurity	Dr Laura Boykin Prof Roger Jones Prof Ian Small
Characterising Genes for Wheat Quality	2015	UWA UQ Bilateral Research Collaboration Award	Prof David Edwards
Oxygen Signalling in Grapevine Bud Dormancy	2015-2017	ARC Discovery Projects	A/Prof Michael Considine, Prof Christine Foyer, Prof Timothy Colmer, Dr Daniel Gibbs, Dr Pieter Verboven, Prof John Considine
Evolutionary Dynamics and the Transformation of Rural Australia	2015-2018	ARC Discovery Projects	Prof Matthew Tonts, Prof Paul Plummer, Dr Neil Argent

Title	Funding Period	Funding body	Supervisors
Exploiting natural variation to discover tools to increase crop plant yield	2015-2017	ARC Discovery Projects	A/Prof Martha Ludwig, A/Prof Brian Atwell, Dr John Lunn, Prof Mark Stitt
Understanding Biological Farming Inputs	2015-2017	CSIRO ex GRDC	Dr Sasha Jenkins
Improved subterranean clover seed production from multiple disease resistance	2015-2017	RIRDC	Prof Martin Barbetti, Dr Philip Nichols, Prof William Erskine, Dr Parwinder Kaur
Soil Microbial Processes and Soil Carbon for Dairy Pastures Amended with Compost	2015	South West Catchments Council (NHT)	E/Prof Lynette Abbott, Dr Sasha Jenkins, Mr Ian Waite, Dr Zakaria Solaiman
Scoping study for agricultural development policy review for Vietnam food security	2015	ACIAR	Dr Elizabeth Petersen
Emerging Foliar Diseases of Canola	2015-2017	GRDC	Prof Martin Barbetti
Australian Herbicide Resistance Initiative - Phase 5	2015-2019	GRDC	Prof Stephen Powles
Membrane transporters mediating 2, 4-D resistance in Wild Radish	2015-2018	ARC Linkage	Prof Stephen Powles, Mr Andrew Wells
Defining the Brassica Pan-genome and Establishing Methods for Gene Conversion Based Crop Improvement	2014-2016	ARC Linkage	Prof Jacqueline Batley, Prof David Edwards, Mr Benjamin Laga
An International Collaborative Effort to Sequence the Genome of Field Pea (Pisum Satiuvum) A Key Tool for Future Breeding	2014	Curtin University ex GRDC	Prof Jacqueline Batley, Prof David Edwards
National Brassica Germplasm Improvement Program – Phase II	2015-2019	GRDC	Dr Sheng Chen, Hackett Prof Kadambot Siddique, Prof Wallace Cowling
Do increased herbicide use impact on key soil biological processes?	2014-2017	NSW DPI ex GRDC	Dr Gavan McGrath
Development of Lupin Molecular Markers Tagging Yield QTL Genes & Yield Related Phenology Traits	2015-2018	DAFWA ex GRDC	Dr Matthew Nelson
Impact of Compost Carbon on Lettuce Growth and Soil Fertility	2015	C-WISE	Dr Zakaria Solaiman,
Reducting stable fly emergence in soils amended with litter	2015-18	Rural Industries Research & Development Corporation (RIRDC)	Dr Sasha Jenkins, Dr David Cook, E/Prof Lynette Abbott, Mr Ian Waite,
Establishing Novel Breeding Methods for Canola Improvement	2015-17	ARC Linkage Projects	Prof Jacqueline Batley, Prof David Edwards, Mr David Pike, Dr Harsh Raman, Dr Stephen Rae
Towards genome methylation based crop improvement	2015-17	ARC Linkage Projects	Prof David Edwards, Prof Jacqueline Batley, Mr David Pike, Mr Benjamin Laga,

Title	Funding Period	Funding body	Supervisors
Impact of Weeds on Australian Grain Production & Adoption of No Till Cropping Practices	2015	CSIRO Ex GRDC	Dr Michael Renton
New Uses for Existing Chemistry	2015-19	University Of Queensland Ex GRDC	Dr Michael Walsh,
Organic Matter and Nutrient Availability	2015	University Of Queensland Ex GRDC	Dr Louise Barton, Prof Daniel Murphy, Dr Fran Hoyle, Dr Craig Scanlan,
Innovative Approaches to Managing Subsoil Acidity in the Western Region	2015-19	DAFWA Ex GRDC	Prof Zdenko Rengel, Mr Paul Damon,
Spatial Temperature Measurement and Mapping Tools to Assist Growers, Advisors and Extension Specialists Manage Frost Risk at a Farm Scale	2015-17	CSIRO Ex GRDC	Dr Kenneth Flower, Mr John Callow, Dr Bryan Boruff,
The new Soil Quality ebook	2015	DAFWA	Prof Daniel Murphy
Impact of Weeds on Australian Grain Production & Adoption of No Till Cropping Practices'	2015	CSIRO Ex GRDC	Dr Michael Renton,
Interdisciplinary Wheatbelt Service Learning Unit	2015	Heartlands WA Ex Wheatbelt Development Commission	Prof Fiona Haslam-McKenzie, Prof Matthew Tonts, Prof Carolyn Oldham, Dr Antony Hughe-D'Aeth
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
Genetic Analysis of Seed Dormancy for Pre Harvest Sprouting Resistance in Wheat	2015	YITPI Foundation PTY Ltd	Prof Guijun Yan, Dr Hui Liu, Hackett Prof Kadambot Siddique

New PhD research students

Ten students commenced their postdoctoral studies in agriculture and related areas at UWA in 2015.

Name	Topic	School	Supervisor(s)	Funding Body
Xiaodong Mu	Flystrike	Animal Biology and IOA	Prof Graeme Martin and Assoc/Prof Shimin Liu	DAFWA
Candy Taylor	The impact of domestication on genes for key phenological traits in lupin (*Lupinus angustifolius* L.)	Plant Biology and IOA	Prof Wallace Cowling and Assoc/Prof Matthew Nelson	APA Award and GRDC
Dina Hermawaty	Organelle biogenesis in grapevine bud dormancy	Plant Biology and IOA	Dr Michael Considine, Dr Patricia Agudelo-Romero, Dr Monika Murcha E/Prof John Considine Prof Christine Foyer	self-funded
Jolene Otway	Assessment of Carbon Cucling and Sequestration Potential in Agricultural Soils	School of Earth and Environment and IOA	E/Prof Lynette Abbott, Prof Daniel Murphy, Dr Jennifer Dungait (Rothamsted Research)	Robert and Maude Gledden Postgraduate Research Scholarship
Xingyi Wang	Genetic Analysis of Seed Dormancy for pre-harvest sprouting resistance in wheat	School of Plant Biology and IOA	Prof Guijun Yan, Prof Kadambot Siddique, Dr Hui Liu	Full fee paying M Phil. student
Roopali N Bhoite	Identification of major QTLs conferring metribuzin tolerance in wheat	School of Plant Biology and IOA	Prof Guijun Yan, Hackett Prof Kadambot Siddique, Asst/Prof Ping Si	APA scholarship
Md Sultan Mia	Pyramiding biotic and abiotic stress tolerant genes by fast generation and molecular marker assisted selection in wheat	School of Plant Biology and IOA	Prof Guijun Yan, Dr Hui Liu	Endeavour Scholarship
Solomon Maina	Establishing the extent and significance of viruses with wind-borne insect vectors arriving from nearby countries and establishing in northern Australia	School of Plant Biology, School of Chemistry and Biochemistry, Plant Energy Biology, and IOA	Prof Roger Jones	CRC for Plant Biosecurity
James Wainaina	Improving food security in Kenya by controlling whiteflies on the common bean	School of Chemistry and Biochemistry, Plant Energy Biology, and IOA	Dr Laura Boykin, Prof Ian Small, Prof Laura Kubatko, Dr Paul De Barro	APA
Rasha Al-Saedi	Determination of design criteria to maximise nutrient removal by vertical flow-through wetlands	School of Civil, Environmental and Mining Engineering and IOA	W/Prof Keith Smettem, Hackett Prof Kadambot Siddique	Iraqi Government Scholarship

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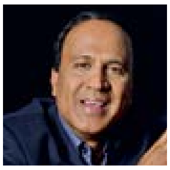

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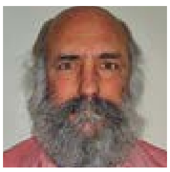

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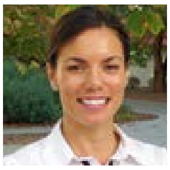

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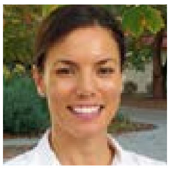

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Refereed journals

1. Abberton M, Batley J, Bently A, Bryant J, Cai H, Cockram J, Costa de Oliveira A, Cseke LJ, Dempewolf H, De Pace C, Edwards D, Gepts P, Greenland A, Hall AE, Henry R, Hori K, Howe GT, Hughes S, Humphreys M, Lightfoot D, Marshall A, Mayes S, Mguyen HT, Ogbonnaya FC, Ortiz R, Paterson AH, Tuberosa R, Valliyodan B, Varshney RK and Yano M (2015) Global agricultural intensification during climate change: a role for genomics. *Plant Biotechnology Journal* pp 1-4

2. Abbott LK, Manning DAC (2015) Soil health and related ecosystem services in organic agriculture. *Sustainable Agriculture Research* **4**: 116-125

3. Abdullah AS, Aziz MM, Siddique KHM and Flower KC (2015) Film antitranspirants yield in drought stressed wheat plants by maintaining high grain number. *Agricultural Water Management* **159**: 11-18

4. Ahmad N, Khan MB, Farooq S, Shahzad M, Farooq M and Hussain M (2015) Potassium nutrition improves the maize productivity under water deficit conditions. *Soil and Environment* **34**:15-26.

5. Almasudy AM, You MP, Barbetti MJ (2014) Influence of fungicidal seed treatments and soil type on severity of root disease caused by *Rhizoctonia solani* AG-8 on wheat. *Crop Protection* **75:** 40-45

6. Ammar MH, Anwar F, El-Harty EH, Migdadi HM, Abdel-Khalik SM, Al-Faifi SA, Farooq M and Alghamdi SS (2015) Physiological and yield responses of faba bean (*Vicia faba* L.) to drought stress in managed and open field environments. *Journal of Agronomy and Crop Science* **201:**280–287

7. Anderson WK and Siddique KHM (2015) The role and value of crop residues in dryland agriculture *Indian Journal of Agronomy* **60** (3): 332-340.

8. Angus JF, Kirkegaard JA, Hunt JR, Ryan MH, Ohlander L and Peoples MB (2015) Break crops and rotations for wheat. *Crop & Pasture Science* **66:** 523-552

9. Anil B, Tonts M and Siddique KHM (2015) Strengthening the performance of farming system groups: perspectives from a Communities of Practice framework application. *International Journal of Sustainable Development & World Ecology*, DOI: 10.1080/13504509.2014.1003153.

10. Anil B, Tonts M and Siddique KHM (2015) Grower Groups and the Transformation of Agricultural Research and Extension in Australia. *Agroecology and Sustainable Food Systems* **39**(10): 1104-1123, DOI: 10.1080/21683565.2015.1081857

11. Anawar HM, Akter F, Solaiman ZM, Strezov V (2015) Biochar: An Emerging Panacea for Remediation of Soil Contaminants from Mining, Industry and Sewage Wastes. *Pedosphere* **25:** 654-665

12. Ashworth MB, Walsh MJ, Flower KC and Powles SB (2015) Identification of glyphosate-resistant *Lolium rigidum* and *Raphanus raphanistrum* populations within the first Western Australian plantings of transgenic glyphosate-resistant canola. *Crop & Pasture Science* **66:** 930-937

13. Asthir B, Thapar R, Farooq M and Bains NS (2015) Biochemical responses of thiourea in ameliorating high temperature stress by enhancing antioxidant defence system in wheat. *Russian Journal of Plant Physiology* **62**:884–892

14. Bajaj D, Das S, Upadhyaya HD, Ranjan R, Badoni S, Kumar V, Tripathi S, Gowda CLL, Sharma S, Singh S, Tyagi A and Parida SK (2015) A genome-wide combinatorial strategy dissects complex genetic architecture of seed coat colour in chickpea. Frontiers in Plant Science, *Plant Genetics and Genomics*

15. Barbetti MJ, Li CX, Banga SS, Banga SK, Singh D, Sandhu PS, Singh R, Liu SY and You MP (2015) New host resistances in *Brassica napus* and *Brassica juncea* from Australia, China and India: Key to managing Sclerotinia stem rot *(Sclerotinia sclerotiorum)* without fungicides *Crop Protection* **78:** 127-137

16. Barton L, Wolf B, Rowlings D, Scheer C, Kiese R, Grace P, Stefanova K and Butterbach-Bahl K (2015) Sampling frequency affects estimates of annual nitrous oxide fluxes. *Scientific Reports*

17. Blackwell P, Joseph S, Munroe P, Anawar HM, Storer P, Gilkes RJ, Solaiman ZM (2015) Influences of Biochar and Biochar-Mineral Complex on Mycorrhizal Colonisation and Nutrition of Wheat and Sorghum *Pedosphere* **25:** 686-695.

18. Borger CPD, Hashem A and Powles SB (2015) Manipulating crop row orientation and crop density to suppress *Lolium rigidum. Weed Research* **56**: 22-30.

19. Busi R, Girotto M and Powles SB (2015) Response to low-dose herbicide selection in self-pollinated *Avena fatua. Pest Management Science* DOI 10.1002/ps.4032

20. Castello M, Stefanova K, Nichol PGH, Nutt BJ, Revell CK, Croser JS (2015) *In vitro* reproduction in the annual pasture legumes subterranean clover (*Trifolium subterraneum* L.) and French serradella (*Ornithopus sativus* Brot.). *Grass and Forage Science*, doi: 10.1111/gfs.12147.

21. Chai Q, Gan Y, Zhao c, Xu HL, Waskom RM, Niu Y and Siddique KHM (2015) Regulated deficit irrigation for crop production under drought stress. A review. *Agron Sustain. Dev* DOI: 10.1007/s13593-015-0338-6

22. Coles N (2015) Water Industry (Law) Reforms: The adoption of Australian drinking water guidelines in Western Australia – from targets to aspirations. *New Water Policy and Practice Journal* **1**(2): 68-83

23. Considine MJ, Sandalio ML, Foyer CH (2015) Unravelling how plants benefit from ROS and NO reactions, while resisting oxidative stress. *Annals of Botany* **116:** 469-473.

24. Coutts BA and Jones RAC (2015) Potato virus Y: contact transmission, stability on surfaces, and inactivation with disinfectants. *Plant Disease* **99**: 387-394.

25. Cowling WA (2015) The challenge of breeding for increased grain production in an era of global climate change and genomics. *World Agriculture* **5**(1): 50-55

26. Cowling WA, Stefanova KT, Beeck CP, Nelson MN, Hargreaves BLW, Sass O, Gilmour AR and Siddique KHM (2015). Using the Animal Model to Accelerate Response to Selection in a Self-Pollinating Crop. *G3:Genes|Genomes|Genetics.* **5:** 1419-1428 doi:10.1534/g3.115.018838.

27. De Blasio MJ,Boije M, Vaughan OR, Bemstein BS, Davies KL, Plein A, Kempster SL, Smith GCS, Charnock-Jones DS, Blache D, Wooding FBP, Giussani DA, Fowden AL and Forhead AJ (2015) Developmental Expression and Glucocorticoid Control of the Leptin Receptor in Fetal Ovine Lung *PLOS ONE* **10**(8)

28. Đalović I, Đorđe J, Chen Y, Bekavac G, Šeremešić S, Jaćimović G, Brdar–Jokanović M (2015) Maize nutrient uptake affected by genotype and fertilization. *Genetika* **47**(3)

29. Das S, Upadhyaya HD, Bajaj D, Gowda CLL, Sharma S, Singh S (2015) Genome-wide insertion-deletion (InDel) marker discovery and genotyping for genomics-assisted breeding applications in chickpea *DNA Research* 1-10.

30. Das S, Bajaj D, Saxena MS, Upadhyaya HD, Badoni S, Kumar V, Tripathi S, Gowda CLL, Sharma S, Parida SK and Tyagi AK (2015) A genome-scale integrated approach aids in genetic dissection of complex flowering time trait in chickpea *Plant Molecular Biology* DOI 10.1007/s11103-015-0377-z.

31. Dias de Oliveira E, Palta JA, Bramley H, Stefanova K and Siddique KHM (2015) Elevated CO2 reduced floret death in wheat under warmer average temperatures and terminal drought *Frontiers in Plant* Science doi.org/10.3389/fpls.2015.01010.

32. Didham RK, Barker GM, Bartlam S, Deakin EL, Denmead LH, Fisk LM, Peters JMR, Tylianakis JM, Wright HR and Schipper LA (2015) Agricultural intensification exacerbates spillover effects on soil biogeochemistry in adjacent forest remnants. *PLoS ONE* DOI:10.1371/journal.pone.0116474

33. Doran-Browne N, Eckard R, Behrendt R and Kingwell R (2015) Nutrient density as a metric for comparing greenhouse gas emissions from food production. *Climatic Change* **129**: 73-87.

34. Duc G, Agrama H, Bao S, Berger J, Bourion V, De Ron AM, Gowda CLL, Mikic A, Millot D, Singh KB, Tullu A, Vandenberg A, Vaz Patto MC, Warkentin TD and Zong X (2015) Breeding Annual Grain Legumes for Sustainable Agriculture: New Methods to Approach Complex Traits and Target New Cultivar Ideotypes, *Critical Reviews in Plant Sciences*, **34**:1-3, 381-411, DOI:10.1080/07352689.2014.898469

35. Erskine, W, Ximenes, A, Glazebrook D, da Costa M, Lopes M, Spyckerelle L, Williams R and Nesbitt H (2015) The role of wild foods in food security: The example of Timor-Leste. *Food Security* **7:** 55-65 DOI: 10.1007/s12571-014-0406-9

36. Farooq M, Hussain M, Wakeel A and Siddique KHM (2015) Salt stress in maize: effects resistance mechanisms, and management. A review. *Agronomy for Sustainable Development* **35**:461-481 DOI 10.1007/s13593-015-0287-0.

37. Farooq S, Shahid M, Khan MB, Hussain M and Farooq M (2015) Improving the productivity of bread wheat by good management practices under terminal drought. *Journal of Agronomy and Crop Science* **201**: 173–188.

38. Fan JW, Du YL, Turner NC, Wang BR, Fang Y, Xi Y, Guo XR, Li FM (2015) Changes in root morphology and physiology to limited phosphorus and moisture in a locally-selected cultivar and an introduced cultivar of Medicago sativa L. growing in alkaline soil. *Plant Soil* **392:** 215-226

39. Faucon MP, Houben D, Reynoird JP, Mercadal-Dulaurent AM, Armand R and Lambers H (2015) Advances and perspectives to improve the phosphorus availability in cropping systems for agroecological phosphorus management. *Adv. Agron.* **134:**51-133

40. Feng S, Su Y, Dong M, He X, Kumaresan D, O'Donnell AG, Wu J and Chen X (2015) Laccase activity is proportional to the abundance of bacterial laccase-like genes in soil from subtropical arable land. *World J Microbiol Biotechnol*

41. Fischer K, Dieterich R, Nelson MN, Kamphuis LG, Singh KB, Rotter B, Krezdorn N, Winter P, Wehling P and Ruge-Wehling B (2015) Characterization and mapping of *LanrBo*: a locus conferring anthracnose resistance in narrow-leafed lupin *(Lupinus angustifolius L.)* *Theor Appl Genet* DOI: 10.1007/s00122-015-2572-3

42. Fisk LM, Barton L, Jones DL, Glanville HC and Murphy DV (2015) Root exudates carbon mitigates nitrogen loss in a semi-arid soil. *Soil Biology & Biochemistry* **80**: 380-389

43. Fisk LM, Maccarone LD, Barton LB and Murphy DV (2015) Nitrapyrin decreased nitrification of nitrogen released from soil organic matter but not *amo*A gene abundance at high soil temperature. *Soil Biology & Biochemistry* **88:** 214-223

44. French RJ, Malik RS and Seymour M (2015) Crop-sequence effects on productivity in a wheat-based cropping system at Wongan Hills, Western Australia. *Crop & Pasture Science* **66:** 580-593

45. Gandy MN, Corral MG, Mylne JS and Stubbs KA (2015) An interactive database to explore herbicide physicochemical properties. *Organic & Biomolecular Chemistry* DOI: 10.1039/c5ob00469a

46. Gao HJ, Yang HY, Bai JP, Liang XY, Lou Y, Zhang JL, Wang D, Zhang JL, Niu SQ, Chen YL (2015) Ultrastructural and physiological responses of potato (*Solanum tuberosum* L.) plantlets to gradient saline stress. *Frontiers in Plant Science* **5:**787. Doi: 10.3389/fpls.2014.00787

47. Ge XT, You MP and Barbetti MJ (2015) Virulence differences among *Sclerotinia sclerotiorum* isolates determines host cotyledon resistance responses in Brassicaceae genotypes *Eur J Plant Pathol* **143:** 527-541

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Acronyms

ACIAR	Australian Centre for International Agricultural Research
ACME-BI	Australian Co-operative and Mutual Enterprise Business Index
AEGIC	Australian Export Grains Innovation Centre
AISRF	Australia-India Strategic Research Fund
ANABP	Australian National Apple Breeding Program
APA	Australian Postgraduate Award
APO	Animal Protection Organisations
ARC	Australian Research Council
AWI	Australian Wool Innovation
BCCM	Business Council of Co-operatives and Mutuals
BLUP	Best linear unbiased prediction
CAAS	Chinese Academy of Agricultural Sciences
CBH	Co-operative Bulk Handling (company)
CERU	Co-operative Enterprise Research Unit
CGIAR	Consultative Group for International Agriculture Research
CSIRO	Commonwealth Scientific & Industrial Research Organisation
COGGO	Council of Grain Growers Organisation
COST	European Cooperation in Science and Technology
DAFF	Department of Agriculture, Fisheries and Forestry
DAFWA	Department of Agriculture and Food, Western Australia
DNA	Deoxyribonucleic Acid
DPI	Department of Primary Industries
DSS	Decision Support System
EDM	Edible Dry Matter
ELLE	Efficient livestock with low emissions
FCR	Fusarium Crown Rot
FFS	Farmer Field Schools
FGS	Fast generation system
FHH	Female-headed households
FNR	Luxembourg National Research Fund
FSS	Food Safety Standards
FTSW	transpirable fraction of soil water
GCMS	Gas Chromatography Mass Spectrometry
GGS	Gnangara Groundwater System
GHG	Greenhouse Gas
GRDC	Grains Research and Development Corporation
GnRH	Gonadotrophin-releasing hormone
GSHIMC	Grains Seed and Hay Industry Management Committee
HIA	Horticulture Innovations Australia Limited
HIF	heterogeneous inbred family
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IMK-IFU	Institute of Meteorology and Climate Research, Atmospheric Environmental Research
IOA	The UWA Institute of Agriculture
IWC	International Water Centre
LAT	Laser Ablation Tomography imaging
LBCS	Legume-based cropping systems
MDA	malondialdehyde
MHH	Male-headed households
MLA	Meat and Livestock Australia
MOU	Memorandum of Understanding
NGO	Non-governmental Organisation
NILs	Near isogenic lines
NLMP	National Livestock Methan Program
NSW-DPI	New South Wales Department of Primary Industries
NT	No-tillage
P	Phosphorus
PCD	Programmed Cell Death
PSU	Pennsylvania State University
PSbMV	Pea seed-borne mosaic virus
QTL	Quantitative trait locus
RCA	UWA Research Collaboration Award
RELRP	Reducing Emissions from Livestock Research Program
RILs	Recombinant inbred lines
RIRDC	Rural Industries Research and Development Corporation
RNA	Ribonucleic Acid
RPP	Ruminant Pangenome Project
RSPCA	Royal Society for the Prevention of Cruelty to Animals
SARDI	South Australian Research and Development Institute
SCaRP	Soil Carbon Research Program
SHR	Systemic Hypersensitivity
TFP	Total factor productivity
TT	Terms of tradeg
TuMV	Turnip Mosaic Virus
UAV	Unmanned aerial vehicle
UNE	University of New England
UWA	The University of Western Australia
WALFA	Western Australia Lot Feeders' Association
WAMMCO	Western Australia Meat Marketing Co-operative
WANTFA	Western Australian No-Tilliage Farmers Association
WS	Water-stressed treatment
WW	Well-watered treatment
WUN	Worldwide Universities Network

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