THE UNIVERSITY OF WESTERN AUSTRALIA

The UWA Institute of Agriculture

Annual Research Report 2014

Sustaining productive agriculture for a growing world

Vision

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

Mission

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

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

Strategies

- Integration: Bringing together the University's agricultural research and communication activities; integrating complementary activities across disciplines and organisational units, and providing a focus for leading-edge research, development, extension and adoption (RDE&A).
- Communication: Strengthening communication links with regional industry, farmer groups and the broader regional and scientific communities.
- Connecting: Fostering national and international linkages and alliances that bring new knowledge and expertise to Western Australia, and allow Western Australia to share its knowledge with the world.
- Resourcing: Increasing the pool of resources available for investment in critical RDE&A in Western Australia and in relevant national and international issues.

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The UWA Institute of Agriculture Annual Research Report 2014

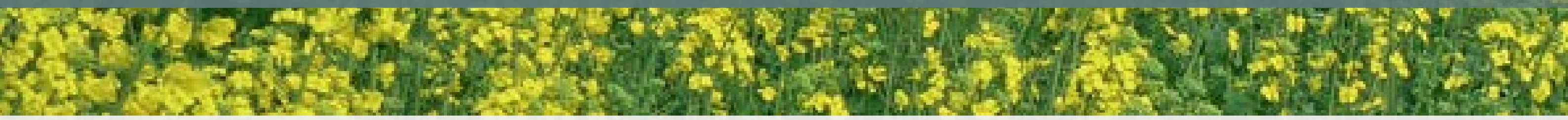
Executive Summary

The UWA Institute of Agriculture (IOA) 2014 Annual Research report summarises some of the highlights of research outcomes, collaborations, training and outreach activities conducted by IOA's researchers in agriculture and related areas.

Now in the eighth year since IOA's establishment, 2014 was a year of progress which saw IOA continue to deliver on its mission to advance research, education, training and communication in agriculture and resource management, for the benefit of mankind.

Early in the year, IOA held a strategic planning day in which representatives from across UWA exchanged ideas on IOA's strategic direction over the next five years, to capitalise on existing strengths and provide focus for new initiatives.

Agriculture at UWA received substantial recognition over the year and in the 2014 Shanghai Jiao Tong University's internationally recognised Academic Ranking of World Universities (www.shanghairanking.com), UWA climbed to 24th in the world for Life and Agricultural Sciences, the highest ranking in Australia.



IOA's achievements during 2014 have been collated within our five research programs.

Integrated Land and Water Management has generated valuable new information on building soil carbon in the sandy soils of Western Australia, how it affects soil nitrous oxide emissions, and how to manage the biological, physical and chemical constraints to soil carbon storage.

Significant progress was made with new technologies for water resource assessment in a changing climate. For example, underground wireless sensor networks, in which sensors, radio module and power sources are buried up to 1m underground, have been studied to prevent damage by machinery when the equipment is above ground.

Plant Production Systems is made up of a large number of projects that ultimately focus on dealing with a variable and changing climate. One of our strengths has been in abiotic stress related research, such as drought, heat and salinity resistance and genomic approaches for stress tolerant crops. Biotic stress related research which aims to improve disease resistance in crop plants was also a key focus of research. Diseases cause large losses in crop yield so improving disease resistance is key to improving food and nutritional security.

Animal Production Systems pursues a vision of clean, green and ethical systems for livestock management. Research into reducing methane emissions in livestock to minimise the environmental footprint through greenhouse gas emissions continued. This was achieved through the international coordination of the Ruminant Pangenome Project, and investigating the mechanism of antimethanogenic bioactivity of plants in the rumen as examples.

Breeding for temperament in sheep is seen as a tool for improving the welfare, where a calm temperament allows ease of handling, productivity and a lesser response to stressors. Researchers tested whether selection for temperament in sheep affect the normal pattern of cortisol secretion.

Rural Economy, Policy and Development has focussed on improving rural productivity and prosperity to enhance the sustainability of rural industries, communities and regions. The grain industry in Western Australia is exposed to price volatility and yield variability. To help farmers manage these risks, yield prediction models have been developed to help farmers predict yield and price risk.

Other highlights in this program include research into benchmarking the performance of farm enterprises and novel business structures for adaptation to a changing climate. A topic of much debate in 2014 were attitudes towards foreign investment in Australian farms. This was investigated in mixed crop-livestock farms in WA.

Internationally, the economics of groundwater for irrigation in Pakistan and the economics of rice production and consumption in Sri Lanka were investigated along with developing novel diagnostics for cassava viruses and whiteflies to improve food security in sub-Saharan Africa.

Education, Outreach and Technology Exchange highlights IOA's commitment to training and leadership, to facilitate the adoption of new technologies and practices nationally and internationally.

Our achievements in education are reflected this year by the numerous awards bestowed upon our researchers and the ten PhD students who commenced their research training in 2014.

IOA secured funding for 60 new research projects and its research was published in 251 refereed journals, 24 book chapters and six books.

Throughout the year, IOA distributed 37 media statements, organised several public lectures, including major events such as the annual Postgraduate Showcase and Industry Forum.

UWA Farm Ridgefield, near Pingelly hosted numerous outreach and teaching activities with school groups and visiting students. One of the highlights was a visit to the farm from Hon. Minister for Agriculture Ken Baston in May 2014.

I would like to acknowledge the dedication and hard work from everyone involved in IOA research and training activities, our national and international collaborators, funding bodies, Institute managements and advisory boards and industry partners who have made these achievements possible.

Professor Kadambot Siddique AM, CitWA, FTSE, FAIA, FNAAS

Hackett Professor of Agriculture Chair and Director
The UWA Institute of Agriculture
The University of Western Australia

1. Integrated Land and Water Management Program

Of the global challenges that society currently faces the basic requirement to feed the increasing world population is of critical importance. Farming systems that are based on sound scientific and practical knowledge need to be designed to support an environmentally and economically sustainable Australia, while addressing the need for soil, water and food security. This necessitates that benefits from applied fertilisers are maximised while off-site impacts, including nutrient flow to waterways and greenhouse gas emissions, are minimised. At the same time the climate is altering and farming systems need to be able to respond to climate change and variability.

Within the Integrated Land and Water Management Program researchers within The UWA Institute of Agriculture (IOA) are collaborating with leading national and international organisations to address these global concerns.

Underground wireless sensor networks (UWiN)

Project team: Prof Rachel Cardell-Oliver[1] (leader; email: rachel.cardell-oliver@uwa.edu.au), Prof Mark Rivers[1], Prof Christof Hübner[2]

Collaborating organisations: [1]UWA; [2]University of Applied Sciences Mannheim (UASM)

The UWiN project will research underground wireless sensor networks in which sensors, radio module and power source are all buried up to 1m underground. Information from distributed sensors is vital for large-scale applications in sustainable agriculture and environmental management, but conventional sensor networks have components exposed above the ground where they can easily be damaged by machinery, stock or weather conditions. An invisible underground wireless sensor network would be the ideal solution to these problems.

The objectives of the UWiN project are to develop and evaluate: (i) radio communication modules for underground transmission; (ii) novel compression and forward error correction algorithms for energy-efficient data transmission from underground; (iii) nutrient and carbon dioxide sensor systems for underground operation; (iv) thermal energy harvesting modules for long-lasting, autonomous sensor network operation; and (v) integration of the results of i to iv into an end-to-end reliable and accurate UWiN system for precision agriculture and environmental monitoring.

Researchers from UWA and UASM undertook research, design and integration of the components of UWiN in bench trials and field trials over four exchange visits. UWA's IOA researchers assisted with the field-based components of the project and ensured that field sites are representative of important farm and catchment system types and

Underground Wireless Network Sensor

that there is pre-existing field-based data to validate and calibrate UWiN.

During July 2014 IOA staff assisted research staff in Mannheim and soil moisture data was sensed and transmitted wirelessly underground for over 100m.

Work is continuing.

This project is supported by the German Academic Exchange Service (DAAD).

New technologies and enhanced techniques for water resource assessment in a changing climate

Project team: Prof Mark Rivers[1] (leader; email: mark.rivers@uwa.edu.au), Prof Neil Coles[1]

The overall aim of this project is the development of wirelessly networked sensor technologies and their implementation in a variety of field locations to allow improved soil and water resource assessments.

Sensors and associated wireless networks have now been developed for chloride, and sensors for nitrate and phosphate are now being investigated.

The WUN-funded development phase of the project has now been completed. The project attracted a large number of additional partners and several of these partners are now actively involved in continued sensor development. In particular, the University of Leeds is now leading a consortium of universities, including UWA, and is installing a large suite of soil and water sensors and associated networks at its research farm in the UK.

This project is supported by the Worldwide Universities Network (WUN).

Development of wirelessly networked sensor technologies

Underground wireless soil carbon dioxide sensors

Project team: Prof Mark Rivers[1] (leader; email: mark.rivers@uwa.edu.au), Prof Christof Hübner[2], Prof Neil Coles[1], Dr Klaus Spohrer[3]

Collaborating organisations: [1]UWA; [2]University of Applied Sciences Mannheim (UASM); [3]University of Hohenheim

Following the success of the UWiN and associated projects, links developed with UASM and the University of Hohenheim are now leading to further research opportunities in the area of wireless monitoring of soil and water data.

Soil carbon dioxide (CO_2) sensors which have been developed by the University of Hohenheim and associated underground wireless data networks which have been developed by the University of Mannheim are being installed at the Wokalup campus of the WA College of Agriculture and are being used to monitor atmospheric CO_2 exchange at high temporal and spatial resolutions.

This information is valuable in terms of both better quantifying atmospheric CO_2 flux mechanisms and optimising pasture management techniques through improved understanding of plant photosynthesis and respiration processes.

This project is supported by DAAD and Harvey Water.

Time domain reflectometry soil moisture sensors for improved irrigation scheduling

Project team: Prof Mark Rivers[1] (leader; email: mark.rivers@uwa.edu.au), Prof Christof Hübner[2], Prof Neil Coles[1]

Collaborating organisations: [1]UWA; [2]University of Applied Sciences Mannheim (UASM)

Following the success of the UWiN and associated projects, links developed with UASM are now leading to further research opportunities in the area of wireless monitoring of soil and water data and the use of these data to control irrigation systems.

Novel (time domain reflectometry) soil moisture sensors are being installed at the Wokalup campus of the WA College of Agriculture and are being used to monitor water movement through irrigated fields at high temporal and spatial resolutions.

This information will then be used to optimise irrigation activities by triggering irrigation equipment automatically based on soil moisture criteria.

This project is supported by DAAD and Harvey Water.

Effectively utilising water allocations for managing turfgrass in open spaces

Project team: Assoc/Prof Louise Barton[1] (leader; email: louise.barton@uwa.edu.au), Prof Tim Colmer[1], Mr Sam Flottmann[1]

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;

UWA Turf Research Facility, Shenton Park.

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: (i) investigating if turfgrass can be maintained with a water allocation (7500kL ha^{-1} $year^{-1}$), and the implications of further lowering the allocation on turfgrass quality; (ii) evaluating how an annual water allocation is best distributed during the year; and (iii) assessing if using a wetting agent can improve the effectiveness of a water allocation.

Our second year of field assessment was completed in 2014. Preliminary findings indicate 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. The suitability of irrigation strategies evaluated in our first two years will continue to be assessed for another year.

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

Applying tillage treatment at the Liebe long-term soil biology trial where nitrous oxide emissions research was conducted.

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

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

Collaborating organisations: [1]UWA; [2]Department of Agriculture and Food, Western Australia (DAFWA); [3]Institute of Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU)

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 carbon (C) sequestration. However, increasing soil C via tillage practices can alter soil GHG emissions depending on the soil type.

Understanding the effect of increasing soil C 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 is to investigate if increasing soil organic C increases N_2O emissions from a cropped soil at Buntine in the Western Australian (WA) grain belt by measuring emissions for two and a half years using automated chambers.

In 2014 we completed collecting two years of N_2O emissions data. Preliminary findings indicate increasing soil organic C has increased N_2O emissions at Buntine, with greatest emissions occurring following summer and autumn rain. However, after two years of measurements the annual emissions remain low (0–0.28kg 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 16.8kg 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 (WA) grain belt.

This project is supported by the Australian Government and the Grains Research and Development Corporation (GRDC).

Managing biological, physical and chemical constraints to soil carbon storage

Project team: Dr Deirdre Gleeson[1] (leader; email: 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[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 for overcoming constraints to C storage in coarse-textured agricultural soils. It builds on the Federal Government's previous Soil Carbon Research Program (SCaRP) Western Australian component which highlighted that the surface soil layer (0 to 10cm) of many of WA's agricultural soils was largely saturated and that if further gains in soil C storage are to be made then soils at depth (10 to 30cm) need to be targeted. The project will assess the potential to increase soil C via management practice – 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.

Dr Yoshi Sawada samples soils at Badgingarra — a soil inversion trial being run in collaboration with DAFWA

We are investigating lime management as a strategy to overcome constraints on C storage in acid soils and to assess the impact of liming and liming history on soil C, decomposition and soil organic matter (SOM) stability. During 2014 we sampled from a number of liming trials across WA, in collaboration with DAFWA staff, to assess the long-term impact of liming on soil C. This data will inform liming strategies with respect to soil C stocks. We are also conducting laboratory incubation studies at both UWA and La Trobe University in Victoria to assess the impact of historical liming, liming rate and lime placement on soil C turnover.

We are comparing claying to the emerging practice (in the context of C stability) of soil inversion (by one-off mouldboard ploughing or spading) for influence on soil C storage capacity. In addition to the surface 10cm soil layer being already C saturated, C and nitrogen (N) cycling are slower at depth than on the surface. Thus burying SOM through mouldboard ploughing and spading has potential for increasing C storage in soil as the buried SOM may decompose at a slower rate and the resulting surface 10cm may have a C content below saturation. During 2014 we sampled from a number of soil inversion trials as well as a claying trial and this knowledge will be used to assess the impact of these soil engineering technologies on soil C levels.

This project is supported by the Australian Government Department of Agriculture.

Management of micro-organisms to unlock the phosphorus bank in soil

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

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

This project aims to provide the agricultural sector with management options to harness soil micro-organisms to unlock part of the $10 billion worth of fixed phosphorus (P) in Australian arable soils and to utilise P fertilisers more efficiently. We aim to achieve this by determining whether microbial release and plant uptake of fixed P in soil can be increased by managing the carbon-to-nitrogen (C:N) ratio of organic matter inputs. During 2014 we focused on finalising our study on the influence of plant residue C:N ratio on the P release capacity of the soil microbial community. We report that organic matter inputs with a low C:N ratio increased microbial biomass and abundance and generally decreased diversity. Further analysis of our experimental data will show whether the use of organic matter inputs with a low C:N ratio, which produces this larger microbial biomass, will increase plant access to fixed P in soil.

In collaboration with Dr Terry Rose from Southern Cross University we have established an incubation experiment to assess the impact of legume rotation on the P uptake and growth of a subsequent wheat crop. We hypothesise that legumes efflux large amounts of C from their root systems during the growing season, which assists in the build-up of large microbial populations. The turnover of this microbial pool during the growth of the subsequent wheat crop may then provide the crop with more P, which may result in better crop growth. We are currently testing this hypothesis by growing wheat, faba bean and narrow-leafed lupin in a variety of soil types (sandy, clay, loam) with and without P amendment.

In collaboration with the University of New England we have established an experiment to visualise in three dimensions (3-D) the impact of management on soil structure and how this impacts on P movement in sandy soils. Using computer aided tomography (CT) scanning we will be able to rebuild a 3-D image of a soil core and visualise the location of P fertiliser granules with respect to plant root growth.

This project is supported by the GRDC and the Australian Research Council Future Fellowship Scheme.

Maintenance of soil organic carbon levels supporting grain production systems

Project team: Dr Frances Hoyle[1] (leader; email: frances.hoyle@agric.wa.gov.au), Prof Daniel Murphy[1], Dr Yichao Rui[1]

Collaborating organisations: [1]UWA; National Soil Carbon Program (NSCP)

Long-term viability of sequestering carbon (C) in soil hinges on the stability and availability of C to micro-organisms in the soil. Although some of the biological mechanisms influencing C and nitrogen (N) turnover have been identified, information is still required on the soil C levels (quality and quantity) required to maintain long-term C storage in agricultural soils. In this project we aimed to: (i) investigate the influence of C on critical soil functions; and (ii) assess the influence of farm management practices and environment on mechanisms driving

Richard Bowles (UWA) doing Mid-Infrared spectroscopy (MIR) scanning of soil samples at DAFWA

C and N turnover (as influenced by the physical and chemical environment) and the associated potential for greenhouse gas fluxes.

While prior modelling for the 0–0.3m soil layer suggests additional capacity for soil C storage, it appears as though individual soil layers are nearing or at saturation (0–0.1m layer). This suggests future management to encourage soil C storage should be targeted at subsoil layers or providing a new surface for C to be stored. Actual yields across WA's wheatbelt region are generally a fraction of their rainfall limited yield potential (40 to 70%) and thus significant gains could be made by increasing water use efficiency in crops and pastures to increase net primary productivity through either improved agronomic management or soil amelioration. Laboratory incubation results suggest that while the light fraction component of organic matter was highly significant in terms of biological activity and process rates, the large differences in background soil organic matter status were more influential. However, the influences of organic matter fractions on soil functions may decline with increasing clay content of soil.

The feasibility of managing soil organic C stocks is most likely beneficial where soil constraints or agronomic benefits have identified an economic benefit to this strategy and, in the case of engineering soils, where there is little risk of erosion. The experimental findings will be broadly applicable in a dryland winter cropping environment with similar soil types.

The data has also been used (in combination with other data sources) by DAFWA within a soil–landscape mapping framework to produce a state of the environment map and report card for soil organic C stocks (0-0.1m) in WA. The project has undertaken an economic evaluation of managing soil organic C.

This project is supported by DAFWA and the Australian Government Department of Agriculture.

High water levels in the Mayfield drain result in movement of P and other nutrients into the Peel Harvey Estuary

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

Project team: Prof Megan Ryan[1] (leader; email: megan.ryan@uwa.edu.au), Prof Hans Lambers[1], Mr Dion Nicol[1], Asst/Prof Carlos Ocampo[1], Prof Edward Barrett-Lennard[1], Prof Mark Tibbett[2,3], Prof Phillip Brookes[2,3]

Collaborating organisations: [1]UWA; [2]Cranfield, UK, [3]Rothamsted Research, UK

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

This project investigates 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).

A meeting of most project participants occurred at UWA early in 2014. Present were representatives of all linkage partners and other interested community groups. Research to date was reviewed and research plans for 2014 were presented and discussed. Our main area of focus in 2014 was to gain a greater understanding of the distribution and forms of P within the landscape. To achieve this, after gaining permission from landholders and local councils, more than 400 soil samples were taken from 108 hand-augured soil cores at 0 to 5, 5 to 20, 20 to 50 and 50 to 100cm. The structure of the sampling was a crossed design of three soil types by three land uses. The three soil types were: deep sand (Gavin series), sand over clay duplex (Coolup series) and clay soils (Turkey flats with two of the sites being heavy Greenland clay). The three land uses were: remnant bush, beef enterprise (low management intensity) and dairy enterprise (high management intensity). These soil samples have been subjected to a Hedley's sequential P extraction (resin P, NaOH extractable P, HCl extractable P, strong HCl extractable P). Some of the questions we hope to answer are: which soil P forms predominate at each depth of each soil type and land use compared to native soil, and which combinations of soil type and land use pose the greatest risk for P losses?

This project is supported by an Australian Research Council (ARC) Linkage Project with Greening Australia, the Harvey River Restoration Taskforce, DAFWA, Alcoa Farmlands and the National Measurement Institute. Greening Australia provided funding originally granted by the Alcoa Foundation.

Determination of mechanisms for alleviating plant water stress involving arbuscular mycorrhiza, through enhancing soil–plant–water availability

Project team: Mr Bede Mickan[1] (leader; email: bede.mickan@research.uwa.edu.au), E/Prof Lynette Abbott[1], Dr Zakaria Solaiman[1], Hackett Professor Kadambot Siddique[1]

This project is determining the potential of arbuscular mycorrhiza (AM) fungi to enhance soil–plant water relations and investigating the complex biological mechanisms involved. The ability of AM fungi to access water unavailable to plants is a potential biological mechanism that can be exploited in dryland agricultural areas. AM fungi may also have an added benefit for soil–water relations by increasing connectivity between individual plants. This project is investigating how AM fungi function to facilitate plant and soil interactions through land management practices.

A decrease in water availability under soil disturbances has been investigated in relation to changes in AM fungi in roots and their hyphal network in soil. This targeted direct water exploitation through AM fungi, and the effect of disturbing soil in water-limited environments. Additionally, soil amendments with compost and clay were used to assess the effect on the rhizosphere bacterial and AM fungi population.

Commensalism between pairs of C3 legume and C4 non-legume grasses has the potential to facilitate C and nitrogen(N) transfer between donor and receiver plants via networks of AM fungal hyphae. The decision to use C3 and C4 plants was based on their alternate temporal niche to reduce competition between the two plants, because C4 grasses are dormant during cold conditions and C3 temperate plants are active in cooler weather. While there is evidence that N and C can be transferred between plants species facilitated by AM fungi, there is still much deliberation on the relative contribution of N transported, and it is unlikely that there is sufficient N transferred between plants to overcome a nutrient deficiency.

This project is supported by an Australian Postgraduate Award.

Polymers for improving soil moisture management and cropping productivity

Project team: Prof Daniel Murphy[1], (leader, email: daniel.murphy@uwa.edu.au), Dr Falko Mathes[1], Dr Jeremy Bougoure[1], Dr Matthias Leopold[1], Dr Gavan McGrath[1], Ms Mary-Anne Lowe[1], Prof Tony O'Donnell[1], Assoc/Prof Peta Clode[1], Assoc/Prof Louise Barton[1]

Collaborating organisations: [1]UWA; CRC Polymers; CSIRO; University of New England; Swinburne University of Technology

The management of non-wetting and poorly wetting soils represents a significant limitation to achieving the yield potential appropriate for about 30% of Australia's cropping lands, which now only produce about 10% of the nation's broadacre crops. Failure to reach their water-limited yield potential arises primarily from run-off and poor furrow efficiencies. Polymeric materials provide the potential to

Soil disturbance decreases plant growth and arbuscular mycorrhiza colonisation under water deficit.

manage these effects through their ability to control water infiltration and transport across the furrows and within the seed–root zone (rhizosphere) and the general soil biota. The output from these studies will be a range of polymers for improving cropping productivity through management of soil moisture, controlling soil wettability, nutrient delivery and optimising the physical, chemical and biological responses both in the plant root zone and the general soil biota.

In general, a key approach this year has been to concentrate on WA wheat belt soils with known non- and poor wettability across the research effort at the three universities and CSIRO. Commonality of soil samples has allowed outcomes from the various research specialisations to be progressively drawn together.

Preliminary examination of surfactant behaviour with these key WA soils showed that a diagnostic strategy could be assembled which defines the main processes involved in water infiltration and transport in different soil types. Model polymer surfactants have successfully shown that the molecular form of polymers can be formulated to improve initial water infiltration, capillary distribution within the soil and re-wetting during subsequent rainfall. The influence of model surfactants on the progression of the wetting front within soil, and preferential wetting which causes inhomogeneous moisture distribution affecting wheat root zones, has been quantified by micro-computed tomography (micro-CT) scanning, where measurements simulated seasonal water deficiency. Model surfactants were used to establish the relationship between surfactant type and migration of surfactant during follow-up rains. Large-scale laboratory replication of field furrows in WA, together with simulated rainfall conditions and electrical resistivity tomography, successfully showed that surfactant formulations can now be verified under different cropping profiles while not reliant on seasonal variations. The suite of diagnostic tests developed now shows why the application of surfactants over the broad range of non- and poorly wetting soils has frequently yielded inconsistent improvements. This has led to the conclusion that the product base for surfactants for non-wetting soils will be enhanced when contained within a technology package, including a soil diagnostic, used to tailor an optimal formulation to particular on-farm soil characteristics. As a final part to the strategy, research has been initiated to verify surfactant inertness with respect to soil microbial populations in terms of their extent and distribution. This strategy will now be applied to the next season's wheat-soil trials.

Agricultural functionalised soil polymers represent the second part of the strategy to manage soil in underperforming broadacre crop production. The project team has now shown in detailed plant-pot trials that the addition of certain functionalised polymers enhances wheat plant germination and growth when measured as fresh plant wet and dry weights, and that this improvement was independent of the soil microbial population in the plant rhizosphere. Application of these functionalised soil polymers in corresponding research farm plots in both WA and the Australian Capital Territory (ACT) has confirmed such a positive effect, evidenced by more extensive wheat plant-matter growth. WA and ACT farm plots for the 2014–15 wheat season have been further instrumented to provide continuous plant and soil monitoring, which will also address the significant spatial non-uniformity (patches) in plant growth and yield within a paddock. Fundamental understanding of microbial community populations near functionalised soil polymers has been clearly established by laser and electron microscopy using model bacteria as well as WA soil microbial communities. Micro-CT has provided confirmed understanding of the mechanisms associated with functionalised polymers adjacent to the plant rhizosphere, where it was shown to extend rhizosphere functionality.

This project is supported by CRC Polymers.

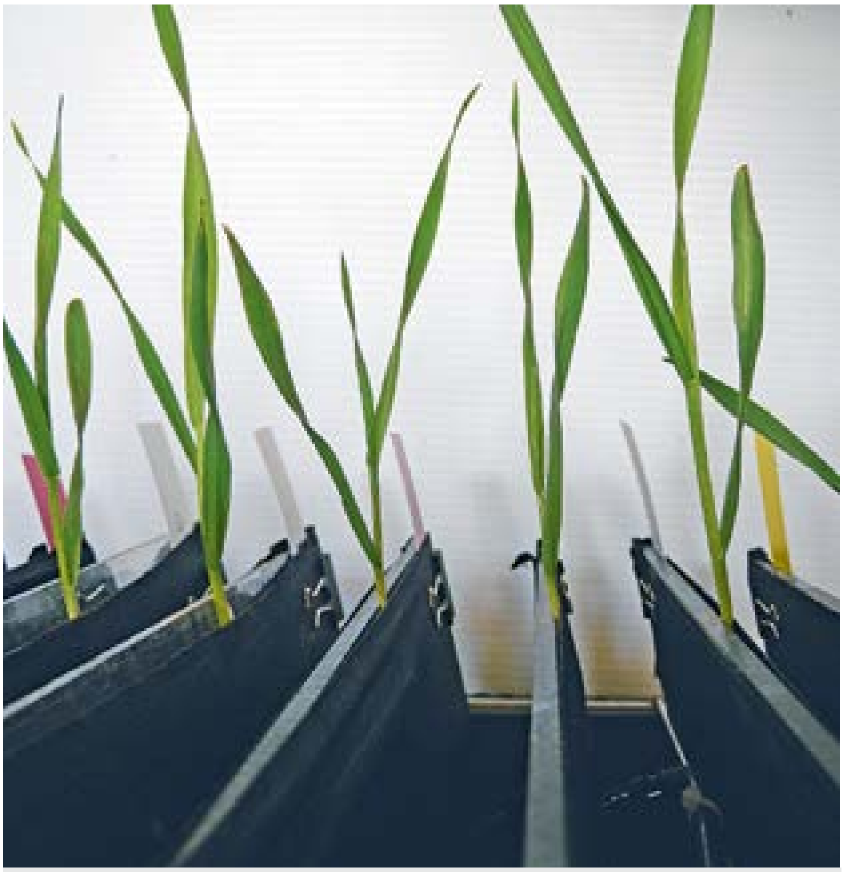
Phenotyping and simulation of barley root architecture for edaphic stress adaptation

Project team: Prof Zed Rengel[1] (leader: zed.rengel@uwa.edu.au), Dr Yinglong Chen[1], Dr Joannes Postma[2], Dr Tobias Wojciechowski[2]

Collaborating organisations: [1]UWA; [2]Forschungszentrum Jüelich (FZJ), Germany

Edaphic stresses such as drought, low phosphorus or low nitrogen availability are the main factors limiting barley production in both Australia and Germany. Breeding cultivars with efficient water and nutrient use for increased adaptation to edaphic stress is an important strategy. However, knowledge on the phenotypic variability in barley root systems is currently lacking. This is partly because dissection of the functions and trade-offs of different root traits with respect to various edaphic stresses is non-trivial.

Barley is the third most important crop in Germany and Australia. However, little is known about how different root system architectural traits influence the relative performance of different barley cultivars in contrasting environments. This project combines intensive phenotyping of root traits with modelling simulation of root architecture and growth in order to: (i) identify phenotypic variability; and (ii) understand how this variability influences nutrient and water acquisition and, eventually, crop growth. The project is designed to provide important information on the phenotypic variability in barley


German barley cultivars in a novel phenotyping platform at a UWA glasshouse

root architecture and barley root system plasticity; it also uses state-of-the-art modelling techniques in order to provide functional and mechanistic explanations for the phenotypic variability.

In 2014 selected cultivars from Australia and Germany were phenotyped for root trait variability using a recently established semi-hydroponic platform. Large diversity in various root traits, including root depth, root length density and number of nodal roots was identified among 14 tested genotypes. The performance of these cultivars was also tested for their adaptation to N and/or water deficiency, and various planting densities in German environments. The phenotypic information will be used to simulate the growth of these cultivars in different environments using the root architectural models developed by the Australian and German partners. The simulation study will allow us to explore how the observed phenotypic variability might affect nutrient and water uptake.

This project will make an important contribution towards understanding the barley root traits with respect to water and nutrient acquisition in dry and low fertility soils. Collaboration between UWA and FZJ creates a unique opportunity in studying barley adaptation to edaphic stresses with specific technological expertise of partner teams in root phenotyping.

This project is funded by Group of Eight (Go8) and DAAD.

Centre for Dryland Agricultural Ecosystems (CDAE)

Project team: Prof Neil Turner[1] (leader; email: neil.turner@uwa.edu.au), Hackett Professor Kadambot Siddique[1], Prof Fengmin Li[2]

Collaborating organisations: [1]UWA; [2]Lanzhou University (LZU), China; International Centre for Agricultural Research in Dry Areas (ICARDA)

In May 2013 the Vice-Chancellor of UWA, Prof Paul Johnson, the President of LZU, Xuhong Zhou, and the Assistant Director General of the International Centre for Agricultural Research in Dry Areas (ICARDA), Dr Majd Jamal, officially opened the Centre for Dryland Agricultural Ecosystems at LZU to increase the cooperation between LZU, UWA and ICARDA in dryland agriculture research and training. Since 2007, Prof Neil Turner has visited the Institute of Arid Agro-Ecology at Lanzhou University, whose Director is Prof Fengmin Li, each year for at least three weeks to work with students and staff on their research projects. For the first six years, Prof Neil Turner visited LZU in September after their experiments were harvested to assist students to analyse, interpret and publish their research in international peer-reviewed journals. It is a requirement of LZU that to be granted a PhD, a student in the Institute of Arid Agro-Ecology must publish at least one paper in an international English-language high-impact journal. Fifty joint papers between students and staff at LZU and UWA have been published since 2007.

In 2014, Prof Neil Turner went to LZU in March/April to discuss experiments and experimental protocols before the experiments were planted. He discussed the aims and protocols of the 2014 experiments with 15 students researching subjects such as: ‘Non-hydraulic root signals and their functional role in drought stress

Semi-arid Loess Plateau of China.

crosstalk in different ploidy wheats'; 'Inoculation with AM fungi induces drought tolerance and increases water availability in dryland wheat'; 'Root morphology and root hydraulic conductance involved in water-saving mechanisms and benefits for yield in soybean under drought'; and 'Soil water changes under nine-year-old leguminous pasture (lucerne) in the semi-arid Loess Plateau of China'. He also began revising three papers for submission to international journals, something that has continued and expanded since returning to Australia.

Several scientists and students have visited UWA under the auspices of the CDAE. In 2014 two PhD students, Ms Junlan Xiong and Mrs Jingwei Fang, have spent 12 and 18 months at UWA as occupational trainees with Prof Kadambot Siddique, Prof Neil Turner and E/Prof Lynette Abbott, respectively. These visits have been supported by the Chinese Scholarship Council and UWA. Additionally Dr Yanlei Du spent six months working with Dr Jiayin Pang and Prof Neil Turner as a Visiting Research Scientist supported by a Chinese Ministry of Education '111' Project to Prof Fengmin Li. The '111' projects, launched in September 2006, aim to invite 1000 academics from the world's top 100 universities to establish 1000 innovative and cooperative research bases in China.

The CDAE is proving to be a useful basis for exchange and cooperation between UWA and LZU in dryland agricultural research.

This project is supported by the Chinese Scholarship Council, Chinese Ministry of Education '111' Project, UWA and ICARDA.

Production and environmental effects resulting from halving the Australian sheep flock from 1989 to 2014

Project team: Adj/Prof Ann Hamblin[1] (leader; email: ann.hamblin@uwa.edu.au), Dr Ivor Awty[2]

Collaborating organisations: [1]UWA; [2]Department of Environment and Primary Industries, Victoria (VIC-DPI)

Grazing has been the most widespread land use in Australia since European settlement, and historically has been responsible for much environmental degradation as well as landscape alteration. In 1989 the national sheep flock was 170 million, 85% of which inhabited the agricultural belt or Intensive Landuse Zone (ILZ). By 2014 the flock had reduced to 74 million, or 43%. Over the same period the national beef cattle herd increased by an equivalent 12 million DSE (dry sheep equivalent) in the ILZ, mostly in the greater than 600mm rainfall belt.

This project aims to review and assess what effects this reduction in flock size has had on pasture extent, condition and productivity across the high rainfall and wheat–sheep zones which together constitute the ILZ, and to examine the potential effect that reduction in grazing pressure may have had on carbon sequestration, remnant vegetation and native biodiversity in the bioregions involved. Possible changes in soil erosion by wind and water, and soil nutrients and pH reaction of pasture soils, are also being investigated. A summary of verifiable gains and losses to agricultural productivity and ecosystem function will be the final outcomes.

During the 25 years of this decline in sheep numbers several other independent factors have influenced the total grazing extent and condition of modified pastures in the ILZ. These include changes to rotational farming systems and herbicide use, the Millennium drought (2002–09) in eastern Australia, persistent decline in winter rainfall in southern Australia, and changed attitudes to biodiversity and natural resource conservation in the community. The degree to which animal production systems have been influenced by these factors is also being taken into consideration.

Preliminary results show the area grazed by stock has remained the largest land use in the ILZ despite the reduction in numbers and an increase of 12 million hectares being cropped. About half the grazed area is rough grazing, not improved pasture. Of the 'improved pastures', originally sown with annual or perennial grass and legume mixtures, two surveys 17 years apart have shown that between 25 and 50% are considered to be in decline, with low (<20%) legume content, high weed burden or unpalatable species. Only 11% have a soil phosphate balance efficiency, 63% are acidic but are oversupplied with phosphate, and reduction in legume content has decreased the amount of organically derived nitrate in the soil, so soils are nutritionally imbalanced. Long-persisting drought conditions led to high levels of wind erosion, irrespective of conservative stocking in parts of south-eastern Australia, in 2002–03 and 2009.

Investment in fertilisers and soil ameliorants such as lime has decreased in the past decade with less than a third of pastures being treated in any one year. The net result appears to be that many pastures are being used inefficiently; average stocking rates have changed little relative to rainfall zone. Many farms that have retained pastures destock seasonally, while rotational grazing rather than set stocking has been encouraged. The evidence for the effect of reduced grazing pressure on C sequestration is mixed. Only where rotational pastures have been converted to permanent pastures is there clear evidence of increased sequestration. Similarly the impact on biodiversity is mixed. While there is evidence of more fencing out of remnant vegetation, planting of native species and better management of modified native grasslands in some districts, clearing of remnant vegetation for increased grazing productivity of pastures persists in Queensland (QLD) and northern New South Wales (NSW).

Preliminary findings suggest that many modified pastures are operating at low productivity, particularly in the medium to low rainfall belts, and direct benefits from reducing grazing pressure on biodiversity and ecosystem function are spatially patchy and inconsistent.

Action on the ground: grazing into the future and building soil health and carbon with pasture management

Project team: E/Prof Lynette Abbott[1] (leader; email: lynette.abbott@uwa.edu.au), Dr Zakaria Solaiman[1], Assist/Prof Natasha Pauli[1], Mr Rob Rex[2], Mr Michael Harcourt-Smith[2], Mr Warren Pensini[2], Ms Sally Thompson[2]

Collaborating organisations: [1]UWA; [2]Bugs and Biology Grower Group

This project investigates innovative on-farm practices to increase the sequestration of carbon (C) in soil through a range of pasture and grazing strategies, including cell grazing management (where pastures are grazed briefly but intensively) and continuously grazed (annual) pastures.

Sketch of sheep grazing by Ann Hamblin.

Annual pasture oversown with perennial grass species (Photo Lyn Abbott)

Perennial grasses may increase soil C storage due to their deeper and more extensive root systems compared with annual grasses, and at the same time decrease soil C losses through erosion. Some studies have reported reduced respiratory loss of soil C in perennial pastures, as perennial pastures can utilise soil moisture from summer rains which would otherwise fuel increased decomposition by soil microbes.

This project studies soil at three properties in WA, situated at Wagin, Woodanilling and Boyup Brook, for a range of pasture and grazing strategies. At Wagin soils are from a sequence of six intensively grazed (cell grazed) permanent pastures containing both perennial and annual pasture species established between 2003 and 2012. During 2014 the team analysed soil samples at the Woodinalling and Boyup Brook sites, and collected a second set of samples from the Wagin site. Additional soil analyses were also carried out on the 2012 field soil collections from the Wagin site in 2014.

In 2014 cell grazed perennial grass pasture was compared with cell grazed annual pasture at the Woodinalling site. There was no difference in soil C (t/ha) between adjacent annual and perennial pastures, at any depth sampled. For the comparison of a cell grazed annual grass pasture with a set stocked annual pasture at the Boyup Brook site, total C in the set stocked annual pasture site was greater than in the adjacent cell grazed annual pasture site at a depth of 0 to 10cm. There were no differences at depths of either 10 to 20 or 20 to 30cm. It was thought that soil properties associated with location in the landscape may influence soil C retention, and this was investigated during 2014 for the Wagin pasture sequence in 2012, but no relationships were identified.

This project has established a monitoring program for soil C that can extend beyond the three years of the project. It recognises that for many farmers, long-term benefits of 'carbon farming' require understanding of how agricultural management practices (pasture management in the case of this project) are related to soil health and productivity.

This project is supported by the Australian Government.

Impact of of LaBC® on biological processes in coarse textured soil

Project team: Dr Sanjutha Shanmugam[1] (leader; email: sanjutha.shanmugam@research.uwa.edu.au), E/Prof Lynette Abbott[1], Prof Daniel Murphy[1]

This project investigated the recycling of biosolids on agricultural land. The use of the lime and clay amended biosolid product, LaBC®,

Example poor establishment of pasture in sandy soil near Bullsbrook, WA used to assess the impact of application of lime and clay amended biosolids (LaBC®) on water repellence. Photo Sanjutha Shanmugam

developed by the Water Corporation Western Australia, was investigated in laboratory, glasshouse and field-scale studies with an emphasis on soil biological processes, either alone or in combination with inorganic fertilisers and a nitrogen (N) absorbing amendment, biochar. The soil used for most of the experiments was a water repellent, coarse-textured, acid sandy soil with poor plant productivity in the field; the land was used for grazing.

There was high spatial variability of LaBC® after application to soil. Inclusion of clay in LaBC® was effective in eliminating soil water repellence even at 50 t ha^{-1} and temporarily suppressed N release from the biosolids. There was no significant N release from soils treated with lime and clay, alone or in combination, in the absence of the biosolids. There may be a complex interaction between, clay, lime and organic matter from LaBC®, but each may have played a dominant role in altering N release from biosolids at different times. Water repellence over time was monitored and water holding capacity was measured and compared with bacterial community structure in soil amended with LaBC®.

The residual effect of LaBC® in coarse-textured sandy soil was assessed in a glasshouse experiment. Plant dry biomass was significantly increased by fertiliser history after five cycles of ryegrass, but there was no residual effect of previously applied LaBC®. The application of LaBC® was further investigated in four soils that varied in pH and nutrient status in a glasshouse experiment. Biochar was added to the soil to determine whether there was an interaction with LaBC®. Addition of biochar decreased N release from LaBC® in all soils. Application of LaBC® had the largest effect on bacterial community structure in the sandy soils compared with the clay soil.

This project was supported by a UWA-SIRF PhD Scholarship and the Water Corporation Western Australia.

Biochar as a soil amendment and habitat for micro-organisms

Project team: Ms Noraini Md Jaafar[1] (leader; email: noraini.jaafar@research.uwa.edu.au), E/Prof Lynette Abbott[1], Assoc/Prof Peta Clode[1], Prof Daniel Murphy[1]

This research sought to determine the role of biochar as a soil amendment and potential habitat for soil micro-organisms, incorporating the use of high resolution microscopy techniques and determining the subsequent interaction of biochars with several soils, soil amendments (organic matter and phosphorus [P] fertiliser) and their effects on soil microbial properties and plant growth. Biochar as a habitat has been suggested as one of the mechanisms which may help promote the microbial status of soil, including activity of arbuscular mycorrhizas. Procedures for observation and quantification of the habitat preferences on biochar were based on use of a range of microscopy imaging techniques.

Woody biochars are a potential habitat for soil micro-organisms due to their high porosity and wide range of pore size based on pore distribution. Biochar retrieved from soil and observed using fluorescence microscopy exhibited distinct hyphal networks on external biochar surfaces.

Soil microbial properties in response to three biochar sources and different biochar particle size were studied under laboratory conditions in an agricultural soil. All three woody biochars provided potential habitat for soil micro-organisms. Soil clumping occurred around biochar particles, cementing and covering biochar pores and surfaces which may have influenced surface area and pore availability for fungal colonisation.

Biochar sources were applied to soils differing in soil C content with subterranean clover. Mycorrhizal

Compost at C-Wise, Mandurah WA (Photo Lyn Abbott)

colonisation of subterranean clover varied with biochar source and other soil amendments (P and a lime–clay–biosolids product). Microscopy evidence demonstrated that biochar could provide a habitat for soil fungi. However, there was little evidence that biochar stimulated microbial activity at soil–biochar–plant–microbe interfaces even in the presence of recently added organic matter from different crops. Mycorrhizal responses after biochar addition to soil varied with soil type, host plant, biochar factors (source, amount, placement method) and interactions with soil amendments.

This project is supported by a Malaysian Government PhD Scholarship.

Development of novel molecular techniques for characterising microbes involved in phosphorus transformations in piggery waste

Project team: Ms Anjani Weerasekara[1] (leader; email: anjani.weerasekara@research.uwa.edu.au), Dr Sasha Jenkins[1], E/Prof Lynette Abbott[1], Prof Tony O'Donnell[1]

This research demonstrated that knowledge of the taxonomic and functional identities of phosphorus (P) mediating bacteria at each stage in the piggery waste water treatment process, together with exploitation of P mineralising bacteria and polyphosphate accumulating organisms, provided a novel strategy for improving the waste treatment process and developing value added fertilisers for land application. It impacts directly upon sustainable agricultural practices by a more effective management of P resources through the potential development of piggery waste by-products (e.g. pelletised piggery compost). From an environmental perspective, the recycling of nutrients from piggery waste and adoption of new practices (e.g. covered anaerobic pond digesters) will reduce waste accumulation and minimise nutrient leaching, both of which are significant risk factors which currently contribute to global eutrophication of water bodies and increased greenhouse gas emissions.

Population and cellular level processes within key treatment stages, microscopy, cell sorting and high throughput DNA sequencing approaches were used to determine the extent to which P mineralisation contributed to P cycling within the piggery waste water treatment system. Key microbes involved in poly phosphate accumulation and the potential for its enhancement under imposed acidic treatments, as a novel strategy for enhanced biological P removal, were also identified.

Pelletised fertilisers derived from remediated piggery waste were investigated with a low rate of inorganic fertiliser to assess plant growth, soil nutrient improvement and fungal–bacterial community composition. Banding of a pelletised composted piggery waste (Balance®) with a granulated inorganic fertiliser (Agras®) was most effective on wheat growth and soil fertility compared to the other soil amendments tested.

This project is supported by a UWA-SIRF PhD Scholarship and the Australian Pork Industry Ltd.

Bioengineering the microbial communities in pig effluent waste to maximise biogas production in retrofitted effluent ponds

Project team: Dr Sasha Jenkins[1] (leader; email: sasha.jenkins@uwa.edu.au), Mr Ian Waite[1], Ms Anjani Weerasekara[1], E/Prof Lynette Abbott[1], Prof Tony O'Donnell[1], Mr Bruce Mullan[2], Mr Hugh Payne[2], Mr Stephan Tait[3], Mr Damien Batstone[3]

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

Effluent waste treatment ponds have been identified as a major source of methane emission in piggeries, accounting for 66% of all greenhouse gas (GHG) emissions across the pork supply chain. One simple and affordable option gaining attention is the possibility of covering these effluent ponds with geosynthetic materials to create a covered anaerobic pond (CAP) digester that both treats the waste and captures the biogas. CAP systems offer a multitude of benefits including GHG mitigation (1 kg CO2-e per kg of pork), renewable energy (~0.5 kW/pig/annum), soil improvers (1 to 3% nitrogen, 0.5 to 4% phosphorus and potassium) and improved community amenity via odour control.

CAP technology is still in its infancy and, while the design risk has been significantly addressed, maintaining process stability is dependent upon a functional microbial community, suitable operating management and environmental conditions.

Our research findings have provided new knowledge about the underlying microbiology in CAPs that governs the bioconversion of waste into biogas. We found that the microbial community is both temporally and spatially stable, able to tolerate a range of temperatures, loading rates (including periods of starvation and shock loads) and waste composition (due to variations in pig diets). The microbial community was dominated by the bacterial taxa *Clostridia, Synergistia* and *Bacteroidia*, which in turn supported a consortium of aceticlastic and hydrotrophic methanogens. These taxa are good candidates for the development of microbial diagnostic tools (e.g. microbial indicators of CAP stability) that could be used to monitor pond performance.

We also sought to find the conditions for optimal microbial growth (and therefore biogas production) and the conditions that brought about microbial inhibition and eventual pond failure. We found that seeding a CAP with an established microbial community conferred community stability during the start-up period and when attempting to recover a failing pond. Seeding was also shown to reduce the lag phase and improve bioconversion efficiency and system stability. The most important factors needed to maintain pond stability and optimum biogas production is avoiding overloading the system and keeping the pH between 5.5 and 8.5. Finally, we found the use of antibiotics as a feed additive did not alter the microbial community composition or inhibit its activity, and anaerobic digestion performance was comparative to the control treatment.

The project is funded by Australian Pork Limited.

Development of microbial indicators of soil quality to quantify the benefits and risks associated with applying piggery by-products to land

Project team: Dr Sasha Jenkins[1] (leader; email: sasha.jenkins@uwa.edu.au), Dr Ian Waite, Ms Anjani Weerasekara[1], E/Prof Lynette Abbott[1], Prof Tony O'Donnell[1], Mr Bruce Mullan[2], Mr Hugh Payne[2]

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

Piggery by-products applied to land using sustainable practices can lead to enhanced crop performance and soil quality (benefits). If applied inappropriately they can potentially cause adverse environmental impacts (risks) such as greenhouse gas emissions, leaching and pathogen survival. However, the true extent of their benefits and risks has not been fully quantified.

This project used state-of-the-art molecular microbiology techniques together with conventional soil quality measures to identify sustainable manure management practices during storage and land application. Ultimately this will enhance the competitiveness of the Australian livestock industries. The data arising from this project suggest that adding piggery waste amendments to soil in combination with synthetic fertilisers at a reduced application rate could enhance nutrient availability for plants. Under these conditions the microbial community structure and function changes, and there was an increase in abundance of genes involved in decomposition and disease suppression which did not comprise plant productivity.

Combined use of piggery waste and other farm wastes could benefit growers by increasing productivity and profitability through improved nitrogen fertiliser use efficiency, soil quality and crop performance, as well as by providing sustainable options for the re-use of agricultural waste. The will contribute to increasing the competiveness of the Australian agriculture industry.

This project is funded by Australian Pork Limited.

Mitigating the greenhouse gas potential of Australian soils amended with livestock manure

Project team: Dr Sasha Jenkins[1] (leader; email: sasha.jenkins@uwa.edu.au), Mr Ian Waite[1], Prof Daniel Murphy[1], Prof Tony O'Donnell[1], Mr Bruce Mullan[2], Mr Hugh Payne[2], Mr Bede Mickan[1]

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

Land application of manures can increase soil carbon but could also increase greenhouse gas (GHG) emissions. The aim of this project is to evaluate the effectiveness of different mitigation strategies at reducing GHG emissions following the application of manure to land.

The lowest emissions were found in soils receiving composted manure, pelletised manure, anaerobically digested manure and covered stockpiled manures. Immediate incorporation at land application further reduced GHG emissions during land application. The nitrous oxide (N_2O) emissions from manure amended soils were likely to be attributed to nitrification and denitrification and were dependent on soil texture and manure type. The field trial is still ongoing but preliminary results suggest that manure amended soils are a potential source of N_2O and a sink for methane (CH_4), and lower manure application rates (5t/ha) may further promote methane uptake.

Pelletising manure followed by composting manure are good strategies for decreasing soil N_2O emissions from semi-arid soils without compromising crop productivity. Overall, composting or pelletising manure are the best management option for mitigating GHG emissions (particularly CH_4) during storage and land application from semi-arid soils in WA without compromising crop productivity and profitability. In collaboration with the Department of Agriculture, Fisheries and Forestry (DAFF) QLD and University of Queensland, we are currently exploring the mechanisms for GHG emissions from manure during storage and land application under different prevailing oxygen concentrations using state-of-the-art molecular and biochemical methods.

This project is funded by the Australian Government.

Understanding biological farming

Project team: Dr Sasha Jenkins[1] (leader; email: sasha.jenkins@uwa.edu.au), E/Prof Lynette Abbott[1], Prof Daniel Murphy[1], Dr Mark Farrell[2]

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

There are a variety of claimed and anecdotally or scientifically observed outcomes from the use of biological farming inputs compared to conventional district practice, ranging from significant negative to significant positive effects on yield and quality of produce. There are many types of amendments, including seaweed extracts, dead or live biological inoculants, composts, manures, and value added products of these, including pelletised forms and extracts such as compost teas.

Across this range of inputs there are several modes of action by proposed amendment producers to explain their own expectations of the products, which are communicated to farmers. These include direct and indirect macro- and micro-nutrient addition through inclusion of microbial inocula to solubilise or fix nutrients, or to aid plant uptake through mycorrhizal associations, stimulation of soil microbial activity and health, and stimulation of root growth through hormones. The purpose of this project is to evaluate, add to and communicate the evidence base for the various categories of biological inputs, and to aid farmers and grower groups in developing methodologies to assess efficacy of biological inputs in their own systems.

We are categorising biological amendments by their proposed mode of action, and then reviewing all available published and unpublished

Compost preparation at C-Wise, Mandurah WA (Photo Lyn Abbott) data to build a picture of the likelihood of these modes of action being effectual in the three GRDC regions (Northern, Southern, Western).

Understanding the underlying biological processes means we will be in a better position to predict how a product might behave for a given soil type and management practice. This information can then be used to determine how best to use the biological product to ensure that benefits in crop yield, soil quality, reduced fertiliser application and disease suppression are achieved.

This project is funded by GRDC.

Establishing the links between higher-fibre diets fed to pigs after weaning, microbial diversity and metabolic function in the gastrointestinal tract, and enhanced gut health

Project team: Prof John Pluske[1] (leader; email: j.pluske@murdoch.edu.au), Dr Sasha Jenkins[2]

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

The aim of this project is to establish whether there is a relationship between the levels of dietary fibre, gastrointestinal tract microbial diversity and function and animal production indices in the post-weaned pig. In a previous project, the effects of two levels of soluble fibre (added as purified non-starch polysaccharides [NSP] from grains) and four levels of insoluble fibre (added as Opticell®) on production indices in *E. coli*-infected pigs were investigated.

Preliminary data suggested little or no effects of soluble NSP on production performance in the first two weeks after weaning. In contrast, the effects of increasing quantities of insoluble NSP in the diet showed significant positive relationships to both average daily gain and average daily feed intake and a reduction in scouring after weaning.

In this project we are implementing state-of-the-art gene sequencing and metabolic profiling technologies, coupled with advanced statistical and modelling approaches to establish links between the levels of fibre and microbial diversity and function in the gastrointestinal tract to production indices and gut health. These relationships will show, for example, whether certain species/genera of bacteria are more closely related to improved production and gut health than others, which in turn creates the basis for improved diet design and the rationale for further probiotic/prebiotic innovation and development.

This project is funded by Pork CRC.

2. Plant Production Systems Program

The Plant Production Systems Program is made up of a large number of projects in various disciplines (e.g. weed science, pasture science, plant pathology, crop physiology and abiotic stress tolerance, genetics and pre-breeding) that aim to contribute to improvements in productivity and sustainability of agriculture.

Most of the research focus is on issues impacting on plant production systems in rain-fed annual temperate crops, and pastures for livestock, but with some work also on perennial plants (e.g. vines) in areas of high rainfall and/or other horticultural crops with irrigation inputs. Current challenges from biotic and abiotic stresses, as well as preparation of robust options in the face of climate change have, again, set the direction for much of the research in 2014, with particular focus on weed management, disease risks, crop adaptation, crop improvement and farming practices.

Improving disease resistance in crop plants

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

Project team: Professor Guijun Yan[1] (leader; email: guijun.yun@uwa.edu.au), Dr Jun Ma[1], Prof Chunji Liu[2], Dr Catherine Feuillet[3], Dr Daniel Mullan[4], Ms Tresslyn Walmsley[4], Mr Jinkao Guo[5], Ms Yanxia Wang[5], Dr John Manners[2], Dr Hui (Helen) Liu[1]

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

Fusarium crown rot (FCR) is widespread and chronic in the 11 million hectare Australian wheat belt, costing nearly $80 million each year in lost production and quality. Growing resistant varieties forms an integrated part of managing this disease but such varieties are not yet available. Our research has previously identified a major quantitative trait locus (QTL) of the disease on wheat chromosome arm 3BL. The aim of this project is to conduct transcriptomic and proteomic characterisations of near isogenic lines (NILs) and develop a large fine-mapping population from the NILs for cloning the genes responsible for FCR resistance and for development of tightly-linked DNA markers for breeding purposes.

In 2014 the focus of the research is to perform fine-mapping of the major 3BL QTL by using the fine-mapping population developed and to conduct DNA and RNA sequencing on the NILs developed in the previous year. The 3BL locus has been placed in an interval of 0.7 cM with the use of 774 NIL-derived lines with seven genes co-segregating with the locus.

To increase the resolution of the targeted chromosome segment on 3BL, we are enlarging the fine-mapping population by genotyping another 2000–3000 of the NIL-derived lines.

Around 1500 lines have been screened so far. Recombinant lines will be used in further mapping the 3BL locus to reduce the interval that QTL is located. As part of the effort in identifying the gene(s) underlying the 3BL locus we are also generating a mutagenesis population. Pure seeds from one of the resistant isolines are being increased in a glasshouse, and we will aim to get a population of about 5000 lines. This population will be used to validate the function of the candidate genes identified in the mapping studies. The same resistant isoline has also been used in sequencing the 3B chromosome. This chromosome has been sorted and a single chromosome library has been constructed. The next step is to get sequences with at least 20x coverage by early 2015.

This project is funded by an ARC Linkage Project.

The response of *Fusarium* crown rot resistance. RR is a resistant line and rr is a susceptible line of wheat

Factors responsible for host resistance to the pathogen *Sclerotinia sclerotiorum* for developing effective disease management in vegetable Brassicas

Project team: W/Prof Martin J. Barbetti[1] (leader; email: martin.barbetti@uwa.edu.au), Ms Margaret B. Uloth[1], Dr Ming Pei You[1], Assoc/Prof Patrick Finnegan[1], Dr Surinder S. Banga[2], Dr Shashi K. Banga[2], Dr Prabhjot S. Sandhu[2]; Dr Huang Yi[3]

Collaborating organisations: [1]UWA; [2]Punjab Agricultural University, India; [3]Chinese Academy of Agricultural Sciences, China (CAAS)

Sclerotinia rot, caused by the fungus *Sclerotinia sclerotiorum*, is a serious disease across vegetable *Brassica* growing regions worldwide, including Australia, with yield reductions of up to 30%. Effective host resistance is urgently needed if *Sclerotinia* rot is to be successfully managed.

The aim of this project is to identify new sources of resistance to *S. sclerotiorum* in selections of *Brassica carinata*, *B. incana*, *B. juncea*, *B. napus*, and *B. napus* introgressed with *B. carinata*, *B. nigra*, *B. oleracea*, *B. rapa* var. *rosularis*, *B. rapa* var. *chinensis*, *B. tournefortii*, *Raphanus raphanistrum*, *R. sativus* and *Sinapis arvensis*.

Against a highly virulent and prevailing pathogen pathotype, the three genotypes with very high-level resistance were all from *B. oleracea* (namely *B. oleracea* var. *italica* 'Prophet' and *B. oleracea* var. *capitata* 'Burton' and 'Beverly Hills'). This is the first report of high-level resistance in *B. oleracea* at the cotyledon stage.

On these resistant *B. oleracea* genotypes, growth of *S. sclerotiorum* on the cotyledon surface was severely impeded, production of appressoria inhibited, and both cytoplasm shrinkage and protoplast extrusion in *S. sclerotiorum* hyphae prevalent. This is the first report of such resistant mechanisms in *B. oleracea*.

Resistant genotypes identified will be of great value not only in furthering understanding of resistance mechanisms across different cruciferous species but also for developing commercial crucifer cultivars with high-level resistance.

This project is funded by ARC and DAFWA.

The range of stem lesion symptoms on *Brassica* species caused by Sclerotinia rot (A) Lesion extending throughout the stem demonstrating a very high degree of susceptibility; (B) and (C) Intermediate sized stem lesions demonstrating moderate resistance; and (D) Hypersensitive reaction displaying the highest level of resistance observed. (Taken from Uloth et al. 2014, *Plant Disease 98: 184-190*)

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

Project team: Prof Roger Jones[1] (leader; email: roger.jones@uwa.edu.au), Prof Michael Renton[1], Ms Brenda Coutts[2], Dr Joop van Leur[3], Mr Benjamin Congdon[1] (PhD student)

Collaborating organisations: [1]UWA; [2]DAFWA; [3]New South Wales Department of Primary Industries (NSW-DPI)

Our national field pea industry is suffering from major losses due to aphid-borne pea seed-borne mosaic virus (PSbMV) epidemics. This project will: (i) collect epidemiological information on this pathosystem, including unravelling the factors that influence aphid vectors within and between growing seasons, their arrival time in crops and virus epidemic development; and (ii) develop an innovative predictive model and decision support system for control. This will improve understanding of factors driving the epidemics, minimise losses, and permit industry expansion to new areas.

In May 2014 field plots were planted at a further two sites each in WA and NSW. Field monitoring for aphid vector numbers and virus spread was undertaken. Aphid and virus samples were collected and tested during weekly visits throughout the growing season. Past aphid monitoring and virus spread data was collated from previous DAFWA field sites in 2010, 2011 and 2012, in addition to data from this project's 2013 sites. This data was related to climatic data for each site in each year. The 2014 field data is currently being collated. The data obtained is being used in the modelling process which is now in progress.

A series of pot experiments are underway to establish the virus transmission efficiencies of relevant aphid vector species, and examine the possibility of wind/contact spread of the virus as an alternative to transmission by aphids. At least two experiments were completed with each of four aphid species commonly found flying over field pea crops and their efficiencies of PSbMV transmission established. Colonies of other aphid vector species are being kept to undertake similar experiments. In addition, transmission of PSbMV at low levels was demonstrated from virus-infected to healthy pea plants in repeated pot tests involving rubbing leaves of infected plants against leaves of healthy ones. It was also demonstrated when spread caused by fans simulated wind currents in glasshouse experiments in which higher levels of virus transmission were obtained. Follow-on experiments are underway looking at the effects of different durations of fanning, plant spacing, row orientation and plant age on the extent of PSbMV spread by simulated wind currents. This information will also be used in the modelling process.

This project is funded by an ARC Linkage grant with DAFWA and NSW-DPI.

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

Project team: Prof Roger Jones[1,2] (leader; email: roger.jones@uwa.edu.au), Prof Martin Barbetti[1], Ms Eviness Nyalugwe[1] (PhD student)

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

Turnip mosaic virus (TuMV) causes diseases that pose a serious threat to *Brassica* oilseed crops and cause major economic losses globally. This project aimed to: (i) 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; (ii) characterise the TuMV resistance phenotypes found and explore the resistance mechanisms involved; (iii) determine the types of inheritance involved in TuMV resistance phenotypes found in *B. juncea;* (iv) establish the biological/genetic diversity of Australian TuMV isolates; and (v) deliver advice to breeders on which TuMV resistances to employ.

This study provided new knowledge about TuMV resistance phenotypes in *B. napus* and *B. carinata*, and the influence of temperature on their expression. It highlighted the inherent dangers in only categorising *B. napus* and *B. carinata* resistance phenotypes in lines grown at a single temperature. It also served as a reminder of the risks associated with only utilising a single pathotype for TuMV resistance screening. Moreover, after sap inoculation with repeated cycles at both low (16 and 18 °C) and high (25 and 28 °C) temperatures complemented by graft inoculations, it revealed uniform phenotype O resistance (extreme resistance) against TuMV isolate WA-Ap1 (pathotype 8) in *B. carinata* (lines IP 117, ST 18 and ST 50) and *B. napus* (line 06-6-3777). It also demonstrated that in plants developing phenotypes R_N (localised hypersensitivity), R (localised infection without systemic invasion) and + (susceptibility) at higher temperatures, low temperature often retards virus multiplication in inoculated leaves to below the level at which it can be detected. Promising lines which displayed phenotype O in more than 75% of inoculated plants included three for *B. napus* (Chinese lines 06-p71-1 and 06-p74-4 and French line Cresor) and six for *B. carinata* (lines Mbeya Green, 30200533, P 295923.3, ML-EM-1, ML-EM-7 and ML-EM-8). Five *B. napus* lines segregated for phenotype R_N especially at higher temperatures (Ding 110, Hyola 42, Fan 028, ZY 007 and Qu 1104). These new resistance sources should be studied under field conditions for their reactions to different pathotypes to obtain information on their overall durability as resistant lines for use in breeding virus resistant cultivars of *B. napus* and *B. carinata*.

The responses of *B. oleracea*, *B. juncea*, *B. rapa*, *Raphanus sativus* and *Camelina sativa* to TuMV pathotype 8 were studied. The predominant phenotypes found in *B. juncea* were: $+_N$ (systemic invasion with some necrosis), $+_{ND}$ (systemic necrosis and plant death), O, R_N, $R_{N/+}$ (necrotic spots in inoculated leaves and susceptible systemic reaction) and +, 22 lines developing only one phenotype, the remaining 47 segregating for two to three different phenotypes. Ten *B. oleracea* cultivars developed phenotype O alone, and one segregated for phenotypes R and O. One *B. rapa* cultivar produced uniform phenotype +, but four segregated for a range of different phenotypes. Two *R. sativus* cultivars developed phenotype O alone, and one segregated for phenotypes O and R_N. All 11 *C. sativa* lines developed uniform phenotype $+_{ND}$. Ten *B. juncea* lines developed $+_{ND}$ (2) or $+_N$ (8) phenotypes uniformly. Increasing temperature from 16 to 28 °C decreased the time lag between inoculation and symptom development without altering overall phenotypic responses in *B. juncea*, *B. oleracea*, *B. rapa* and *C. sativa* plants. When inoculated with pathotypes 7 and 1, phenotypic responses remained the same in *B. juncea*, *B. oleracea* and *B. rapa*, but pathotype 8 caused a different response in *C. sativa.* Genetics of TuMV resistance was studied in a cross between *B. juncea* parents with uniform phenotypes, JM 06006 (+) and Oasis Cl ($+_{ND}$). The results of four tests on F2 progeny plants and three types of control plants (JM 06006, Oasis Cl and mock-inoculated F2 progeny plants) were analysed for their responses to pathotype 8. Segregation of F2 progeny plants from *B. juncea* Oasis Cl X JM 06006 fitted a 3:1 ratio (systemic necrosis: susceptibility) at an early stage of TuMV infection, and a 1:2:1 ratio ($+_{ND}$: $+_N$: +) at a late stage of infection. Therefore a single incompletely dominant resistance gene, designated TuRBJU 01, was responsible for phenotypes $+_{ND}$ (homozygous condition) and $+_{N}$ (heterozygous condition) in *B. juncea*. *B. juncea* resistance gene TuRBJU 01, along with lines of *B. oleracea* and *R. sativus* that developed phenotype O uniformly and of *C. sativa* that developed phenotype $+_{ND}$ uniformly, are suitable for breeding TuMV resistant cultivars.

A phylogenetic study involving whole TuMV genomes revealed that six Australian TuMV isolates originally obtained from five different species in two plant families fitted within the overall world-B group. They were separate from the rest of the group which contained isolates from other continents. The remaining new genome sequence and only other Australian genome fitted within the basal-B grouping. Seven of the Australian TuMV genomes were recombinants while one (isolate NSW-5) was not. Six different recombination events were found among these recombinants, each of which contained one or two such events. This study also revealed major differences in virulence between different Australian TuMV isolates, both within the same hosts and between host species in four different families.

This project is funded by a UWA Scholarship by Research Fees Award.

Typical brown discolouration and swollen stubby roots of subterranean clover cv. Woogenellup following infection by *Aphanomyces trifolii*

Managing soil-borne root disease in sub-clover pastures

Project team: Prof Martin Barbetti[1] (leader; email: martin.barbetti@uwa.edu.au), Dr Xiangling Fang[1], Mr Dion Nicol[1], Dr Alan MacKay[2]

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

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

This project aims to identify effective and practical management techniques to reduce the pasture productivity loss during autumn–winter induced by soil-borne root disease.

Field studies showed cultivation greatly reduces tap and lateral root disease and significantly increases germination, nodulation, and root and shoot dry weights of subterranean clover. Cultivation offers significant prospects for utilisation as an effective option to control root disease.

Characterisation of associations between expression of disease from *Aphanomyces trifolii* with 'environmental factors' showed that this pathogen especially inhibits germination under moderate temperatures and high soil moisture, while it causes most severe root disease at low temperature, high moisture and high nutrition.

Cultivars Guildford-D, Campeda, Urana, and Antas, along with Dalkeith, Riverina and York are the first cultivars identified with resistance to *A. trifolii*. However, there were strong indications of multiple pathogen races with different host genes controlling resistance to damping-off versus tap versus lateral root disease from *A. trifolii*.

DNA assays for identifying *A. trifolii* have been developed and field validated and meaningful application of DNA Predicta B test findings is now possible for the first time for pastures.

This project is funded by Meat and Livestock Australia (MLA).

Studies on virus diseases of cultivated and wild plants of Western Australia

Project team: Prof Roger Jones[1] (leader; email: roger.jones@uwa.edu.au), Ms Brenda Coutts[1,2]

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

This research consisted of two studies on viruses spread by contact, stability on surfaces, and inactivation with disinfectants (one with a cucurbit virus and the other with a potato virus), and a study on the epidemiology of an eryoiphyid mite and seed transmitted virus of wheat. The cucurbit virus, zucchini yellow mosaic virus (ZYMV) studied is important in the subtropical central region (Gascoyne) and tropical north-west region (Kimberley) of WA, while the potato and wheat viruses studied, potato virus Y (PVY) and wheat streak mosaic virus (WSMV), are important in the Mediterranean-type climatic region of south-western WA. Based on this new PhD research, Ms Brenda Coutts was named Researcher of the Year at the 2014 AUSVEG National Awards for Excellence.

ZYMV is one of the most economically important viruses of cucurbit crops worldwide. ZYMV was found to spread from infected to healthy cucurbit plants by leaf contact (rubbing and crushing), and on blades contaminated with infective sap. Also, it remained infective in dried sap at room temperature for up to six hours and for up to 24 hours after drying on some types of surface. However, it was inactivated by several common disinfectants. Cucurbit growers can therefore spread ZYMV from infected to healthy plants inadvertently by moving machinery through crops (e.g. during spraying or fertilising), on weeding implements (e.g. hoes), during harvesting (e.g. on knives) and during crop monitoring (e.g. on footwear or clothing). This highlights the importance of sanitation and hygiene practices in cucurbit production. Measures that address contact transmission such as washing down machinery, disinfecting cutting tools and surfaces and limiting handling and movement within crops have now been included within modified integrated management strategies for viruses of cucurbits.

PVY is the most economically important virus of potato crops worldwide. It is non-persistently transmitted by aphids. There are contradictory reports about whether PVY transmission occurs via plant-to-plant leaf contact and tuber-to-tuber by cutting. In this study, PVY spread readily from infected to healthy potato plants by leaf-to-leaf, to a lesser extent by tuber-to-leaf contact, and to a very limited extent when blades contaminated with infective leaf sap are used to cut healthy potato tubers. There was no tuber-to-tuber transmission when blades were used to cut infected and then healthy tubers. These findings provide evidence that PVY is likely to be transmitted from infected to healthy potato plants through foliage contact between nearby plants when their foliage is damaged by equipment. It also provides evidence that PVY transmission occurs rarely when tubers are cut with blades contaminated with infective sap. PVY remained infective in sap kept at room temperature for up to 28 hours, up to six hours after drying on cotton, hessian and wood, and up to 24 hours on tyres and metal. However, PVY was inactivated by some common disinfectants. Understanding that PVY has the potential to spread through sap contamination on several common surfaces highlights the need to ensure machinery, equipment and clothing are cleaned before moving between crops. This research therefore highlights the importance of sanitation and hygiene practices in seed potato production.

Wheat streak mosaic virus (WSMV) is a major wheat pathogen of grain cropping regions worldwide. The role of seed transmission in providing WSMV inoculum sources for these epidemics was studied. Although it occurred in wheat cultivars, no evidence for it was found in any barley or oats cultivars or in several common annual grass species and it failed to infect any common perennial grasses. Therefore the source of infection for volunteer or sown wheat that germinates following the summer fallow is via seed transmission in wheat itself and this plays a crucial role in the survival and spread of WSMV between growing seasons. In field studies, WSMV spread was localised around simulated seed-borne infection sources regardless of whether the source was internal or external to the wheat planting. Thus, in a Mediterranean-type climate where there is an absence of WSMV infection sources during the hot, dry summer conditions between successive wheat crops, seed-infected wheat seedlings growing as volunteers or from sown infected wheat seed stocks play a critical role in initiating WSMV epidemics. Management strategies suitable for WSMV control were revised to include: (i) sow healthy wheat seed after getting a seed sample tested before sowing; and (ii) ensure no wheat seed is left in the field after harvest of infected crops. To achieve the latter, harvesters can be adapted to collect small seeds that are excluded from the main seed harvest.

This project is funded by DAFWA.

Bean yellow mosaic virus: from Koch's postulates to next generation sequencing and their use to unravel the cause of black pod syndrome of narrow-leafed lupin

Project team: Prof Roger Jones[1] (leader; email: roger.jones@uwa.edu.au), Dr Bevan Buirchell[2], Ms Monica Kehoe[2]

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

Black pod syndrome (BPS) is a syndrome where pods, especially primary pods on the main stem of a narrow-leafed lupin (*Lupinus angustifolius*) plant, prematurely turn black or brown producing few or no seeds. BPS causes low yields of *L. angustifolius* especially in southern coastal WA. It is important to discover the cause so that disease management strategies can be devised, and to help local lupin breeders produce BPS resistant cultivars.

The specific aims of this project were to: (i) identify whether late infection with bean yellow mosaic virus (BYMV) causes BPS and satisfy Koch's postulates over whether it is the causal agent; (ii) obtain BYMV isolates from *L. angustifolius* plants with BPS and determine their molecular and biological properties; (iii) investigate whole genomes of BYMV isolates from plants with BPS through the use of next generation sequencing; (iv) compare whole BYMV genomes from plants with BPS with genomes isolated from other sources; (v) explore the potential threat to *Lupinus* spp. from indigenous potyviruses; and (vi) deliver a set of recommendations and management plans to growers.

In 2011 a survey of *L. angustiolius* plants with BPS from six locations in south-western Australia was conducted. BYMV detection was most reliable when real-time PCR with generic potyvirus primers was used on tissue taken from the main stem just below the black pods. When plants were inoculated with BYMV at eight different growth stages, BPS was only induced when they were inoculated after first flowering when pods were forming. Koch's postulates were fulfilled for the hypothesis that late infection with BYMV causes BPS because it was isolated from a symptomatic *L. angustifolius* survey sample, inoculated to and maintained in culture hosts, inoculated to healthy *L. angustifolius* plants inducing BPS, and then successfully re-isolated from them. Confirmation of BYMV as the cause of BPS constitutes an important step forward in the quest for a BPS resistant *L. angustifolius* cultivar. A control measure needing emphasis is maximising volunteer clover control within the crop and avoiding planting next to or downwind of legume pastures or other crops that contain sources of BYMV.

The question remains over whether related viruses might also cause BPS. The original natural host of hardenbergia mosaic virus *(*HarMV) is *Hardenbergia comptoniana* (native wisteria) which is indigenous to south-western Australia. Two plants of *H. comptoniana* and one of *L. cosentinii*, each with mosaic and leaf deformation symptoms, were sampled from a small patch of disturbed vegetation at an ancient ecosystem–recent agroecosystem interface. After sequencing on an Illumina HiSeq 2000, three complete and two nearly complete HarMV genomes from *H. comptoniana* and one complete HarMV genome from *L. cosentinii* were obtained. The complete genome from *L. cosentinii* differed by only eight nucleotides from one of the genomes from a nearby *H. comptoniana* plant, with only one of these nucleotide changes being non-synonymous. This is the first report of a HarMV example for south-western Australia of virus emergence from a native plant species to invade an introduced plant species.

A comparison of the genomic and biological properties of BYMV isolates from *L. angustifolius* plants with BPS, systemic necrosis or non-necrotic symptoms, and from two other species was conducted. When one isolate of the related clover yellow vein virus (ClYVV) and 22 BYMV isolates were sequenced on the Illumina HiSeq 2000, one new ClYVV and 23 new BYMV sequences were obtained. When the 23 new BYMV genomes were compared with 17 other BYMV genomes available on Genbank, phylogenetic analysis provided strong support for existence of nine phylogenetic groupings. Replacement of the current system of phylogenetic nomenclature based on biological properties by numbered groups (I to IX) was proposed. Biological studies with seven BYMV isolates and one of ClYVV and nine plant species gave no symptoms or reactions that could be used to distinguish BYMV isolates from *L. angustifolius* plants with BPS from other isolates.

Recombination analysis was conducted on the complete coding regions of 33 BYMV genomes and two genomes of ClYVV. This analysis found evidence for 12 firm recombination events within BYMV phylogenetic groups I to VI, but none within groups VII to IX or ClYVV. The greatest numbers of recombination events within a sequence (two or three each) occurred in four groups, three of which formerly constituted the single ancestral generalist group (I, II and IV) and group VI. Sequences in groups III and V had one event each. These findings indicate that recombination explains the very broad natural host ranges of three BYMV groups (I, II and IV) which infect both monocots and dicots, and that the three groups with narrow natural host ranges have the potential to recombine to broaden those natural host ranges.

This project is funded by an Australian Postgraduate Award and GRDC.

Typical above ground symptoms of reddening leaves, poor growth and death of clover severely affected by Phytophthora root disease (LHS); typical root rotting symptoms from Phytophthora (Top RHS); and survey soil samples from across southern Australia being tested to determine the different races of *Phytophthora* present (Bottom RHS)

Making clover pastures permanently resistant to *Phytophthora* root disease

Project team: Prof Martin Barbetti[1] (leader; email: martin.barbetti@uwa.edu.au), Dr Ming Pei You[1]

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

This project aims to define the race situation for *P. clandestina* across southern Australia, identifying which pathogen races are present and in which agro-geographical regions, so that the appropriate subterranean clover cultivar resistances can be located and deployed against the prevailing races in different regions.

Farmer fields sampled and surveyed across southern Australia from late autumn and early winter of 2014 onwards showed that the vast majority not only had a very severe level of taproot rot (with a taproot rot disease index of 60 to 80%), but that they also have extremely severe lateral root rot disease (with a disease index of 80 to 100%).

While *P. clandestina* was found to be widespread across southern Australian subterranean clover pastures it was not universally present in all diseased pastures sampled.

Bioassay testing of survey soil samples has now commenced, using a standard set of seven subterranean clover host differentials developed earlier in WA,to define the nature and distribution of the different races of *P. clandestina* across southern Australia.

This project is funded by Australian Wool Innovation Ltd (AWI).

Characterisation of rice blast races present in Australia

Project team: Dr Vincent Lanoiselet[2] (leader; email: vincent.lanoiselet@agric.wa.gov.au), Prof Martin Barbetti[1], Dr Ming Pei You[1], Dr Peter Snell [3], Dr Andrew Geering[4,5]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]Yanco Agricultural Institute, NSW-DPI; [4]DAFF Queensland; [5]University of Queensland

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

This project aims to investigate the genetic diversity and the prevalence of the rice blast races present in Australia, and to identify and map

Typical above ground symptoms of rice blast on a commercial rice crop in 2014 in Queensland (Photo Ming Pei You) the distribution of rice blast races across Australia, as this is a critical prerequisite step to develop strategies for deploying existing resistant rice cultivars and for breeding new ones.

A high level of genetic diversity exists among rice blast isolates in Australia, with 10 isolates from QLD and WA belonging to five different races.

In race IA-1, cultivars Ceysvoni, BR-IRGA-HO9, Rikuto Norin 20, Yunlu 29 and Quest were susceptible; cultivars SHZ2 and NTR 478 were resistant. In races IA-3, IA-63 and IB-3, all cultivars showed similar responses, with cultivars Yunlu 29 and Quest being susceptible; cultivars Ceysvoni, BR-IRGA-HO9, Rikuto Norin 20, SHZ2 and NTR 564 were resistant. In race IB-59, cultivars Yunlu 29 and Quest had moderate resistance while the others were resistant. In general, cultivars Yunlu 29 and Quest were most susceptible while cultivar SHZ2 was most resistant to all races. Race IA-1 was the most virulent of all cultivars, followed by races IA-3, IA-63 and IB-3, while race IB-59 was least virulent.

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

Genetic analysis of drought resistance in bread wheat (*Triticum aestivum*)

Project team: Professor Guijun Yan (leader; email: guijun.yan@uwa.edu.au), Dr Xuanli Ma[1], Mr Habtamu Ayalew[1] (PhD student), Assoc/Prof Tadesse Dessalegn[2]

Collaborating organisations: [1]UWA; [2]Debre Markos University, Ethiopia

Bread wheat (*Triticum aestivum*) is one of the earliest domesticated cereals and it is currently the second largest cereal crop – in terms of production – in the world, following maize. According to the USDA 2013 report, a total of 221.8 million hectares of land was covered by wheat with a total grain production of 697.01 million metric tonnes in the 2011–2012 cropping season. Global wheat production and productivity has been on the increase in the past years. Nevertheless, the current productivity of wheat, and all other crops, needs to be further increased to feed the ever growing population of the world.

The effort to improve production and productivity of wheat is, however, deterred by different biotic and abiotic stresses. Drought stress is among the most serious environmental constraints limiting crop growth and productivity in many regions. Drought has impacted wheat farmers in Australia and all over the world in the past. Drought can happen at any growth stage of the crop.

With recurrent and long periods of dry spells being more prevalent than ever, the identification of drought tolerant wheat genotypes is the first step to improve and sustain wheat production in most parts of the world. It is becoming more evident that rains are not starting early in the season, or if they do so, interruptions happen for a few weeks after sowing. This has a drastic effect on crop establishment and also pushes the crop growing period to the other stressing period at its reproductive stage (terminal drought). To fit the crop's life cycle into the moist part of the season, the crop has either to establish early so that it has enough time for full growth or it has to be an early maturing (shorter life, which is a low yielder) type to escape the terminal drought.

Genotype identification for yield is not always straightforward as yield is a complex quantitative trait. It becomes even more complex when coupled with drought. This calls for the need to look at various traits that contribute to drought tolerance, which finally helps to improve crop yield.

The major objective of this research project, therefore, is to find genes or genotypes for early growth stage drought tolerance in bread wheat that confer resistance at the seedling (most succulent) stage, so that early crop establishment can be assured to make use of the precipitation to resume later.

With this objective in mind, screening for water stress was carried out in a constant temperature room. A hydroponic system was developed from plastic boxes (3000mL) with holes of about 8mm diameter drilled in lids that supported plant growth on the surface of a solution. Osmotic stress of -0.82 MPa was induced using polyethylene glycol (PEG 6000). Plants were grown in water for the first seven days followed by either in half-strength Hoagland's solution alone (control) or half strength Hoagland's solution and PEG 6000 (treatment).

Data were analysed based on augmented complete block design. The most contrasting genotypes from the first experiment were crossed/hybridised to each other in a diallel fashion to study the different gene actions and to develop mapping populations for further genetic analysis.

This project is funded by AusAID.

Implementation of a newly developed fast generation technology for the Australian wheat/barley breeding industry

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

Collaborating organisations: [1]UWA; [2]Intergrain, SuperSeed Technologies Pty Ltd, CSIRO

Long generation time is one of the major bottlenecks limiting the efficiency of wheat/barley marker development and trait recombination for both pre-breeding and breeding. Doubled haploid (DH) techniques can produce pure lines relatively quickly; however, the success is genotype dependent and expensive and there is only a single opportunity for recombination to occur. The fast generation system (FGS) involves the culture of embryos 10 to 15 days old. By forcing seedling growth and flower differentiation, seeding to flowering period can be shortened to about 30 days. The total time for one generation can be 40 to 45 days, enabling the turnover of eight to nine generations per year. FGS has significant advantages not only over traditional breeding, but also over DH technology. Firstly, this system can be used for all genotypes. Secondly, there is every reason to expect that FGS should give the same recombination as traditional breeding procedures. This system is also useful for researchers wanting to quickly produce populations of recombinant inbred lines (RIL) and/or near isogenic lines (NIL) for many other areas of research. The aims of this project are to develop a reliable FGS on diverse wheat/barley genotypes, to accurately assess the cost of the fast generation system, and to seek improvements to ensure the new system is cost effective, reliable and widely adopted by crop breeding organisations.

In 2014 the focus of the research was to test FGS on a wide range of wheat/barley genotypes and populations. Twenty wheat cultivars and 20 barley cultivars are being tested for their performances of fast generation. Ten individuals of each genotype were tested.

The populations tested include two wheat populations segregating in chlorophyll contents, one wheat population segregating in frost tolerance, two wheat populations segregating in phosphorus efficiency (the pure line has been harvested for downstream experiment), two wheat populations segregating in herbicide tolerance (the pure line has been harvested for downstream experiment) and another six wheat populations and three barley populations obtained from the breeding industry.

A new FGS completely under *in vitro* environment has also been tested with a hope to achieve faster and easier outcomes more suitable for factory scale operation. So far, we have achieved *in vitro* flowering and seedsetting in some wheat genotypes. We are applying the protocol to more genotypes in both wheat and barley. We have tested the effects of different culture media and environment conditions on the *in vitro* fast generation system.

The costs of FGS are being assessed with an aim to provide the service to the cereal breeding industry.

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

Wheat plants flower around 30 days after planting under modified growing conditions

Wheat curl mite and wheat streak mosaic: detection, transmission, epidemiology and management

Project team: Prof Roger Jones[1] (leader; email: roger.jones@uwa.edu.au), Ms Belinda Cox[2], Dr H Luo[1,2], Prof Ary Hoffman[3]

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

Wheat streak mosaic virus (WSMV) and wheat mosaic virus (WMoV) are major wheat pathogens of the world. WMoV causes the same symptoms as WSMV, has the same wheat curl mite vector, and often occurs together with WSMV in the same co-infected wheat plant. *Polymyxa graminis* is the root-infecting fungal vector of soil-borne cereal viruses. It was found in Queensland in 2009 infecting barley roots. It is cause for concern because of the likelihood of rapid spread of damaging soil-borne cereal viruses should they become introduced from overseas. One of these, soil-borne wheat mosaic virus (SbWMV), has reached New Zealand, but none are known to occur in Australia.

The aims of the project were to: (i) develop a real-time PCR test which detects and quantifies WSMV infection in bulk wheat seed samples for use to establish if wheat seed stocks or consignments can be sown, distributed or exported without risk of yield loss, virus dissemination to new locations or failure to meet importers' phytosanitary rules; (ii) develop additional real-time PCR protocols to detect WMoV in wheat seed stocks, three soil-borne wheat viruses in wheat leaf samples and *P. graminis* in wheat root samples; and (iii) establish whether *P. graminis* occurs in the WA grainbelt.

WSMV seed tests must be done on wheat seedlings rather than directly on seed as surface contamination of seed produced on WSMV infected wheat plants does not necessarily imply presence of the embryo virus infection needed to produce infected wheat seedlings. Also, seed samples need to be collected in such a way that they represent commercial wheat seed stocks. A real-time PCR test that detects and quantifies WSMV infection in seedlings grown from bulk wheat seed samples was developed and validated.

Consistent results were obtained for sensitive real-time PCR detection of a single WSMV infected seedling in 5000 and 10,000 bulk seedling leaf samples, and a range of bulk samples simulating different levels of seedling infection up to 1% assay validation was done by testing bulk WSMV infected seedlings by both ELISA and real time real-time PCR. Comparable seed transmission results were obtained by both methods.

Full genome sequences were obtained for two WMoV isolates from wheat in WA, and partial genome sequences for two others. From this sequence data, primers and probes were developed for use with a real-time PCR test to detect WMoV infection in bulk wheat seed samples. The assay reliably detected four WMoV isolates. It was optimised so it could be combined with the WSMV test to detect both viruses in a single tube.

The wheat seedling test protocols developed for WSMV, WMoV and for both viruses together are suitable for use by national seed testing laboratories. Accurate detection of WSMV and WMoV in seed stocks allows growers to remove a major source of both viruses for their spread to and within wheat crops.

Real-time PCR protocols were also developed for testing wheat samples to detect wheat spindle streak virus, soil-borne cereal mosaic virus and SbWMV in wheat leaf samples, and *P. graminis* in wheat root samples. These protocols are suitable for use by national seed testing laboratories. Availability of detection protocols for soil-borne viruses and their *P. graminis* vector means that Australia is in a position to detect these wheat viruses reliably should an incursion occur.

In 2011 and 2012 *P. graminis* was identified infecting wheat root samples from three locations in south-western Australia. Also, when soil samples were collected from two locations where *P. graminis* was found and wheat bait plants were grown in them, *P. graminis* was detected in their roots by PCR. Ribosomal DNA sequences of six south-western Australian isolates were obtained from wheat roots, and one Queensland isolate from barley roots. When these seven *P. graminis* sequences were compared with others from Genbank, three south-western Australian isolates were classified as *P. graminis* f. sp. *temperata* (ribotypes Ia and Ib), and three as f. sp. *tepida* (ribotypes IIa and IIb). Both occur in temperate growing regions of other continents, and are associated with transmission of soil-borne viruses to cereal crops. The *P. graminis* isolate from Queensland was sufficiently distinct to be placed into a newly proposed grouping, ribotype VI, which also included an isolate from tropical West Africa. These findings suggest at least three *P. graminis* introductions into Australia, and that soil-borne cereal viruses are likely to become established should they be introduced.

The effects of high crop residue no-till farming systems on crop diseases and invertebrate populations in a long-term no-tillage experiment

Project team: Ms Cara Allan[1] (leader; email: cara.allan@uwa.edu.au), Dr Ken Flower[1], Hackett Prof Kadambot Siddique[1]

The aim of this project is to determine whether the crop rotation and quantity and type of crop residue affects root and foliar disease levels and beneficial and pest insect populations.

Aphids in wheat

The disease and pest complex in broadacre agriculture may have changed with widespread adoption of no-tillage and increased stubble retention. Other major factors include earlier sowings, new crop and pasture cultivars, changing climate, and increased reliance on insecticides and fungicides.

There is some evidence that soil-borne diseases decrease after some time in no-till cropping systems with residue retention. However, there is little research into the effects of high residue no-tillage farming systems on changes in disease levels and insect population dynamics (i.e. pest and beneficial species) over time. There is also limited knowledge on the changes in disease and insect populations in continuous cereals compared with more diverse rotations.

The Western Australian No-Tillage Farmers Association (WANTFA) along with CSIRO and UWA has an established long-term rotational trial at Cunderdin, with GRDC funding. Trial sites were selected and baseline data obtained from the site in 2006, with the first crops sown at the break of the 2007 season. This site provides opportunity to monitor the level of insect pests and crop diseases.

In 2014 progress was made with respect to insects, foliar disease assessment and root disease.

The findings are as follows.

Insect type and occurrence varies widely between treatment types. Continuous cereal and wheat treatments maintain high insect pest populations, while treatments employing crop diversity in rotation consistently record low insect pest populations. There were no differences between high and low residue retention treatments. Preliminary results indicate pest and beneficial insects reach equilibrium when insecticide application is restricted over the long term.

Regarding foliar disease assessment, low levels of disease were seen in all plots except continuous wheat treatments which recorded increased incidence of flag smut (*Urocystis agropyri*) infection, due to carryover of disease from the 2013 season. There were no differences between high and low residue treatments

Regarding root disease, high numbers of the nematode *Pratylenchus neglectus* were seen in the continuous cereal treatments. Continuous wheat had the highest rating for root disease severity, nematode and *Rhizoctonia*.

This project is funded by the Australian Centre for International Agricultural Research (ACIAR) and GRDC.

Genome sequencing in narrow-leafed lupins

Project team: Prof Karam Singh[1,2] (leader; email: karam.singh@csiro.au), Assoc/Prof Lars Kamphuis[1,2], Assoc/Prof Matthew Nelson[1], E/Prof Craig Atkins[1], Prof Grant Morahan[1]

Collaborating organisations: [1]UWA; [2]CSIRO; Beijing Genomics Institute (BGI), China; Proteomics International, Western Australian Institute of Medical Research (WAIMR)

Narrow-leafed lupin (NLL) is the main grain legume grown in WA and forms an important part of sustainable farming systems, reducing the need for nitrogenous fertiliser, providing valuable disease breaks and boosting cereal yields. In this regard it is a key crop for Australia and particularly WA, the major grain producing state, as it is critical for sustaining WA's large, heavily export-orientated cropping industries. There are exciting opportunities that are opening up through the genomic/sequencing revolution to quickly accelerate NLL breeding. NLL has only been recently domesticated and there is tremendous scope for rapid improvements through applying modern pre-breeding and breeding technologies.

The scope of this project is to provide the research and breeding community with extensive information on the NLL genome sequence. Our major focus is to decipher as much of the gene space sequence as possible and to use this valuable sequence information to greatly accelerate marker discovery and identification of candidate genes of interest for lupin crop improvement.

In 2014 a comprehensive draft genome sequence has provided 620 MB of genome sequence over about 1400 scaffolds. Another three NLL accessions (two domesticated and a wild accession) were re-sequenced and large numbers of simple sequence repeat (SSR) and single nucleotide polymorphism (SNP) markers from the lupin genome/transcritome sequence were generated, and many were converted to Fluidigm markers and used to genotype NLL recombinant inbred line (RIL) populations.

This project is funded by GRDC, CSIRO and UWA.

Genome sequencing of the root infecting fungal pathogen *Rhizoctonia solani*

Project team: Prof Karam Singh[1,2] (leader; email: karam.singh@csiro.au), Dr Jonathan Anderson[1,2], Dr James Hane[2], Ms Angela Williams[1]

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

The root-infecting necrotrophic fungal pathogen *Rhizoctonai solani* causes $77 million damage to wheat and barley crops and significant losses to legumes and canola. Currently there is no effective resistance to *R. solani* in any of its crop hosts. It is vital to investigate *R. solani* in order to discover exactly how it induces disease and how a plant's immune system may be adapted to overcome infection. One of the first steps in this process was to sequence the genome of the fungus, a task which was complicated by the presence of multiple different nuclei in each isolate. These nuclei may contribute to why the fungus is able to infect such a broad range of species. To address these challenges new bio-informatic techniques were developed. The final genome sequence assembly encoded a predicted 13,964 genes and showed a high level of diversity between the nuclei. The amount of genetic diversity held within a single isolate of *R. solani* was found to be greater than that reported when populations of single nuclear fungi of other species were sequenced. With the low rate of sexual recombination expected to occur in the field, this high level of diversity is thought to be driven by the 'RIP-like' mutation process observed in the genome and this may be how *R. solani* is able to infect its great diversity of host plants. The genome sequence has also enabled in-depth analysis of the proteins the fungus may be using to cause disease, with a few of these showing promising leads.


Healthy lupin seedling (left) and *R. solani* AG8 infected lupin (right)

This project is funded by GRDC, CSIRO and UWA.

Resistance strategies for *Rhizoctonia solani* in Australian crops

Project team: Prof Karam Singh[1,2] (leader; email: karam.singh@csiro.au), Dr Jonathan Anderson[1,2], Dr Kathleen De Boer[1], Brendan Kidd[2], Dr Rhonda Foley[2], Dr Yao Liu[2,3]

Collaborating organisations: [1]UWA; [2]CSIRO; [3]Sichuan Agricultural University, China; Sainsbury Laboratory, UK

Rhizoctonia solani causes bare patch, root rot and hypocotyls rot diseases of cereals, legumes and canola in Australia. Internationally it is a major constraint to rice production and has large impacts on maize, soybean, potato, sugarbeet and many other crops. The absence of genetically controlled resistance in host crops means conventional breeding strategies have not previously been effective in producing resistant cultivars. This project has been taking several approaches towards generating resistance to this recalcitrant disease problem.

On the plant side of the interaction we found two lines of evidence suggesting that a class of chemicals called reactive oxygen species (ROS) were important in plant resistance to *R. solani.* Using the genetic resources available in the model plant *Arabidopsis thaliana* we have been investigating the role of ROS. A CSIRO Postdoctoral Fellow, Dr Brendan Kidd, recently joined the team and brings further skills in analysing the role of ROS in plant defence responses. UWA research associate, Dr Kathleen De Boer, and CSIRO senior research scientist, Dr Rhonda Foley, have been working to follow up on some of the earlier findings on defence signalling pathways important for resistance, and translating these into canola, a close relative of *Arabidopsis*.

On the pathogen side of the interaction we have capitalised on our recent *R. solani* AG8 genome sequence to conduct proteomic analysis and re-sequence a number of additional isolates with contrasting pathogenicity profiles. Dr Jonathan Anderson undertook a secondment to the Sainsbury Laboratory in the UK to conduct an analysis of these isolates to identify candidate proteins relating to host range differences. This work identified specific sets of proteins with distinct characteristics, and the function of these on different plants is currently being tested. The team has also been collaborating with Prof Aiping Zheng of Sichuan Agricultural University who works with a rice infecting *R. solani* isolate and co-supervises a PhD student, Yao Liu, who is undertaking a two-year project in the joint UWA–CSIRO Molecular Plant Pathology and Crop Genomics Laboratory. Ms Liu's project investigates differences in the infection processes of the different *R. solani* isolates to better understand early processes in resistant and susceptible responses of plants.

This project is funded by GRDC, CSIRO and UWA.

Physiological basis of drought resistance in chickpea

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

Collaborating organisations:
[1]UWA; [2]Lanzhou University; [2]Australian Centre for Plant Functional Genomics (ACPFG), University of Adelaide; SARDI; University of Queensland; University of Melbourne; RMIT; ICRISAT and several other collaborators in India

Chickpea is now the largest grain legume crop of Australia, grown on over 0.5 million hectares and surpassing lupins. Prior research by various international groups which focused on biotic constraints, such as ascochyta blight, has led to significant gains

Seedlings from a range of crop species being screened for resistance to different *R. solani* isolates

Profs Neil Turner, Kadambot Siddique, Tanveer Khan, Dr Jiayin Pang, Yanlei Du and Junlan Xiong in the UWA Glasshouse

in resistance. An equally significant challenge is improvement of abiotic stress tolerance for further substantial gains in productivity. Abiotic stresses significantly limit chickpea production. Drought alone is estimated to reduce yield by 30% annually, compounded by high sensitivity to heat. This will become more severe under predicted climate change scenarios, and specific breeding and selection for resistance to drought is urgently required.

The overall objective of this project is to identify drought resistant chickpea germplasm and determine the major physiological traits relevant to drought resistance. Field trials at three sites in the WA grainbelt in 2012 and 2013, including more than 100 lines from crosses originated at ICRISAT, displayed large genotypic variation in response to water-limited environments of WA. From the two-year field trials, several genotypes showed consistently high yields across different sites while some had consistently low yields. Ten genotypes with similar flowering time, including four with consistently high yields and four with consistently low yields in both 2012 and 2013, and two commercial cultivars were selected to study the detailed physiological mechanisms for adaptation to terminal drought in the glasshouse during 2014.

During 2014 a large-scale glasshouse experiment was conducted at UWA. A wheelie bin growing system was developed, with plants grown in 80L wheelie bins, each containing 105kg of field soil from near Cunderdin in WA. Growing chickpea in large bins simulated conditions closer to the field and also enabled soil water to last longer once drought was imposed.

A purpose-built balance, with a maximum capacity of 200kg and an accuracy of 10g, was used to monitor soil water content after water stress was imposed, as well as to determine water volumes added to controls. Measurements were made for total water use, soil water content every 10cm down the soil profile using moisture probes, flower and pod abortion, and yield and its components.

Two contrasting genotypes were studied for detailed physiological and morphological traits and mechanisms associated with drought resistance, including leaf water potential, gas exchange characteristics, seed filling rate, the role of abscisic acid (a hormone closely related to drought stress) and other key enzymes in seed development. The gene expression studies related to drought resistance will be conducted in collaboration with colleagues at the University of Melbourne and RMIT.

Preliminary results indicate that when drought stress was imposed at early podding stage, flower and pod abortion were significantly increased in all 10 genotypes leading to reduction in seed yield due to the reduced seed number and seed size. Significant variation in seed yield was found among the 10 genotypes. One genotype used less water during the first 10 days of drought stress and conserved more water for use at later stages. This may have contributed to it having the highest seed yield among the 10 genotypes. Under drought stress, the pod wall reached a maximum dry weight after 23 days of flowering followed by a significant decrease afterwards, while in well-watered plants the pod wall reached the maximum value after 30 days of flowering, with little change afterwards. This indicates that carbohydrate in the pod wall was translocated to the developing seeds under drought stress. When soil water content was reduced to 25% of soil field capacity, both pollen viability and pollen germination reduced significantly in water stressed plants.

This project is funded by the Australia–India Strategic Research Fund (AISRF) Grand Challenge.

Genomic approaches for stress tolerant chickpea

Project team (in Australia): Dr Tim Sutton[2] (leader; email: tim.sutton@sa.gov.au) , Prof Tim Colmer[1], Hackett Prof Kadambot Siddique[1], Assoc/Prof Victor Sadras[3], Prof David Edwards[2], Assoc/Prof Rebecca Ford[5], Dr Nitin Mantri[6], Prof Neil Turner[1], Dr Jiayin Pang[1], Mr John Quealy[1], Mr Hammad Khan[1]

Collaborating organisations: [1]UWA; [2]ACPFG, University of Adelaide; [3]SARDI; University of Queensland; [5]University of Melbourne; [6]Royal Melbourne Institute of Technology (RMIT); ICRISAT and several other collaborators in India (led by Dr Rajeev Varshney)

Abiotic stresses limit chickpea productivity in Australia, India and other countries. IOA scientists are part of a collaborative multi-disciplinary team in Australia and India undertaking research to improve abiotic stress tolerance in chickpea. The focus of the work at UWA is on drought tolerance and salt tolerance. The UWA team has undertaken field and controlled environment phenotyping to identify tolerant genotypes and experiments to elucidate physiological mechanisms contributing to tolerance.

Substantial differences in salt tolerance (measured as seed yield in saline conditions) has been confirmed and the key genotypes identified are being used at UWA in experiments on physiological mechanisms and also transferred to our Australian partners for studies of gene expression and development of populations for genetic studies. The tolerance has been evaluated in salinised soil in pots in repeated glasshouse experiments and also tested in short rows at saline field sites over two years. These two years of field data together with the large glasshouse data sets are currently being analysed.

UWA PhD student Mr Hammad Khan has conducted experiments using nutrient solution cultures in which the types of salts were easily altered and root as well as shoot responses studied. Mr Khan, on behalf of the project team, presented his salinity research results during 2014 in the form of a poster at a Gordon Conference in the USA and as an oral presentation at ComBio2014 in Canberra.

Mr Khan will spend 12 months at ACPFG with Dr Tim Sutton in experiments to identify candidate genes associated with salt tolerance. Joint PhD supervision between partners is making a significant contribution to training of the next generation of pulse breeders, molecular geneticists and physiologists.

Papers from this AISRF Grand Challenge project are currently in preparation. In addition, progress has also been made to complete publications from our preceding smaller AISRF project with ICRISAT – this smaller project that finished in mid-2014, was led by Vincent Vadez at ICRISAT and Prof Tim Colmer at UWA.

This project is funded by the Australia–India Strategic Research Fund (AISRF) Grand Challenge.

Hammad Khan with chickpea growing in the glasshouse

Enhancing the WA chickpea industry through targeted demonstration and extension of new *Ascochyta* resistant improved varieties and lines in partnership with grower groups

Project Team: Hackett Prof Kadambot Siddique[1] (leader; email: kadambot.siddique@uwa.edu.au), Prof Tanveer Khan[1], Mr Alan Meldrum[2]

Collaborating organisations: [1]UWA; [2]Pulse Breeding Australia; WA Grower Groups

Chickpea (*Cicer arietinum*) is the second most widely grown grain-legume in the world, and in the mid 1990s WA developed a rapidly growing chickpea industry which covered about 80,000 hectares by 1999. In the same year, the ascochyta blight disease (caused by the fungus *Ascochyta rabiei*) appeared and the severity of the outbreak caused the industry to all but disappear in WA over the subsequent decade.

New high yielding varieties with resistance to ascochyta blight disease and good seed quality have now become available. This project aimed to rekindle growers' interest in chickpea through targeted demonstrations of new ascochyta resistant varieties in WA.

In 2014 four demonstration trials involving three new varieties (Ambar, Neelam and PBA Striker) along with the control variety Genesis836 were sown using paddock scale machinery and local management practices at Mullewa, Mingenew, East Buntine and Corrigin. In addition, two replicated yield trials of commercial varieties and some near release crossbreds were located at Mingenew and Merredin. At each site the project personnel spoke at the demonstration/variety trials. The key messages, that ascochyta blight disease no longer presented any threat as all new varieties have adequate resistance and that new varieties are also higher yielding and good quality, was delivered directly to over 200 growers and agribusiness consultants who attended these field events. One of the major highlights of these demonstrations was the interest shown in the higher rainfall southern area of Corrigin. In 2014 a survey was conducted to monitor the state of the chickpea industry and get growers' feedback. It was found that while there is considerable interest in chickpea, growers are few and far between. It is interesting to see that some growers did not know that the ascochyta blight resistant varieties are now available. A range of concerns were raised and the two most important were the profitability (as a result of current low prices) and weed control. Further efforts should be made to promote the role of chickpea for sustainable cropping in WA, particularly in areas where options for rotation are limited.

This project is funded by COGGO.

Tanveer Khan at demonstration trial in East Buntine

Exploring the mechanisms of salinity tolerance in chickpea

Project team: Mr Hammad Khan[1] (leader; email: hammad.khan@research.uwa.edu.au), Prof Tim Colmer[1], Hackett Prof Kadambot Siddique[1], Dr Tim Sutton[2]

Collaborating organisations: [1]UWA; [2]ACPFG, University of Adelaide

Salinity impacts crop productivity in Australia and many other countries. Chickpea is very salt sensitive, but genetic variation exists which can be used to improve chickpea yield under moderately saline conditions. The mechanisms of salinity tolerance in chickpea are still not fully understood so there is need to use physiological and molecular biology tools to explore these mechanisms.

To understand tolerance mechanisms it is important to elucidate the ways by which salt stress limits plant growth and yield. Salt stress affects plants primarily by exerting an osmotic stress and/or ion (sodium [Na^+] and/or chlorine [Cl^-]) toxicity. Our experiments this year have evaluated chickpea responses to these factors. In plants, physiological and biochemical changes observed in response to salt stress are driven by transcriptional regulation of numerous genes and with additional controls via post-transcriptional regulations. The identification and characterisation of genes differentially regulated in tolerant and sensitive chickpea genotypes under salt stress has been commenced in our studies, with the aim of identifying genes and tolerance mechanisms that could be exploited in molecular breeding.

Using two contrasting genotypes of chickpea and treatments of different combinations of nutrients and salt types enabled us to conclude that chickpea is not sensitive to the osmotic component of salt stress that can substantially reduce growth, as it can adjust osmotically very well up to 60 mM NaCl external salinity. In addition, it was exciting to observe that chickpea is particularly sensitive to Na^+, and Cl^- is not toxic to chickpea despite reaching higher tissue concentrations than Na^+, at least at the vegetative stage. These results have shown that Na^+ transport and accumulation is an important determinant of sensitivity of chickpea to salinity (i.e. 60 mM Na^+ with various anions in the root zone; Cl^- at this concentration with cations other than Na^+ was not damaging), but nothing is known about the underlying molecular basis for this phenotype. Hence an important next step in this work is to investigate the expression of genes encoding transport proteins or regulatory factors involved in Na^+ transport in contrasting chickpea genotypes. We are collaborating with Dr Tim Sutton at ACPFG to explore the gene expression profiles. We are doing a comparative global transcriptome analysis (using RNA sequencing) for sensitive (Rupali) and tolerant (Genesis836) genotypes of chickpea, grown in control and saline conditions to identify gene transcripts differentially expressed between Rupali and Genesis836. Genes identified will be selected for future functional characterisations.

Contrasting chickpea genotypes, Rupali (left) and Genesis836 (right) grown under 60 mM NaCl stress

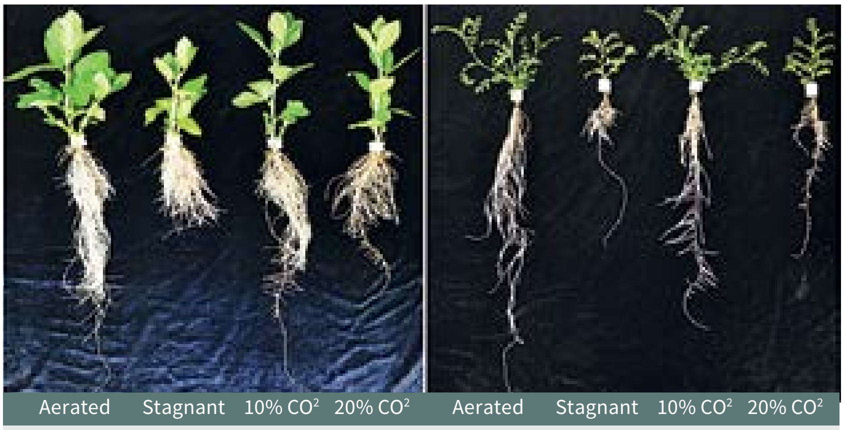
This project is funded by an Endeavour Postgraduate Scholarship and AISRF.

Responses and adaptation of chickpea and faba bean to waterlogging stress

Project team: Ms Rushna Munir[1] (leader; email: rushna.munir@research.uwa.edu.au), Prof Tim Colmer[1], Hackett Prof Kadambot Siddique[1]

Food security for an extra two billion people by 2025 and three billion by 2050 under changing climate conditions is one of the greatest challenges of the twenty-first century. Natural flooding events in Australia not only destroy crops but also pose longer-term impacts such as waterlogging stress on subsequently planted crops. Similarly in Australia's Mediterranean-type environments, winter rains pose transient waterlogging stress to chickpea which is the most important cool season grain legume.

Waterlogged soils are not only hypoxic (i.e. lack oxygen) but also accumulate gases (i.e. high levels of carbon dioxide [CO_2] and phyto-hormone ethylene) and organic acids in the root zone. Literature shows limited information on chickpea sensitivity and physiological responses to different components of waterlogging stress. To understand tolerance mechanisms, it is very important to dissect the contribution of different components of waterlogging stress on plant growth reduction.



Adaptation of chickpea and faba bean to waterlogging stress

From recent results, using two grain legumes with contrasting hypoxia tolerance (i.e. hypoxia sensitive chickpea [poor root aeration] and tolerant faba bean [better root aeration]), we found that both species were sensitive to elevated root zone ethylene concentration and even the hypoxia tolerant genotype faba bean could not benefit from improved aeration. Similar sensitivity was observed when we exposed these species to high CO_2 in the root zone, showing that even if roots can access some oxygen, the high CO_2 accumulation also contributes to growth reduction. However, the extent of growth reductions under root zone gaseous accumulation are not parallel to what we observed in waterlogged conditions, suggesting that organic acid accumulation could also be contributing towards growth sensitivity. Therefore the next step is to examine chickpea and faba bean growth and aeration in response to different organic acids in the root zone.

This project is funded by UWA.

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

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

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

Narrow-leafed lupin (NLL) is a major grain legume crop in WA that has recently been gaining recognition as a human health food. The grain is high in protein and dietary fibre, and 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. A high proportion of seed weight remains within the seed coat compared with other grain legumes (25% for NLL compared to 7% for soybean). A reduction in seed coat biomass may increase availability of resources for the grain, with an associated increase in harvest yield. The grain also accumulates quinolizidine alkaloids, secondary metabolites that play a role in defence from insect predators, but are toxic and must remain below the Australian food and feed standard of 0.02% total alkaloids. Mechanisms of alkaloid biosynthesis, transport and the responses of these to environmental conditions are poorly understood. This project aims to use a genomic approach to assist breeding efforts by identifying and characterising genes involved in seed coat development and in the biosynthesis and transport of quinolizidine alkaloids.

The purpose of the 2014 research was to identify putative genes playing a role in NLL seed coat development, alkaloid biosynthesis and alkaloid transport through the use of newly available NLL genome


Alkaloid research on the grain legume crop Narrow-leafed lupin

Ion toxicities (Al, Mn and Fe) are induced in transiently waterlogged acid soils and impair root and shoot growth in wheat.

and transcriptome sequence data, and then subsequently investigate the expression of these genes within plant organs of seven lupin varieties. The expression of alkaloid genes will be studied in leaves, flowers, stems, roots and stages of seed development, with seed coat genes studied in seed development. This serves to identify sites of alkaloid production and determine how expression levels correlate with varying seed coat phenotypes and alkaloid profiles. This gene expression analysis is ongoing.

We are also screening a TILLING (Targeted Induced Local Lesions IN Genomes) NLL population for mutations in these genes, a method which combines chemical mutagenesis with a DNA screening technique to identify mutations in genes of interest. Once identified, the phenotypic effects of these mutations can be examined and functionality assigned to those genes. To complement this research we have been working in collaboration with the Optical and Biomedical Engineering Laboratory (UWA), using the novel imaging technique of optical coherence tomography in order to rapidly and non-destructively screen mutant seeds for thin seed coat phenotypes to assist in identifying genes with a major role in seed coat development.

This project is funded by CSIRO and UWA.

Investigating tolerance rating of elite breeding lines and commercial wheat varieties to ion (iron, aluminium and manganese) toxicities

Project team: Assoc/Prof Hossein Saberi[1] (leader; email: hossein.khabaz-saberi@uwa.edu.au), Prof Zed Rengel[1]

Ion toxicities (iron [Fe], aluminium [Al] and manganese [Mn]) are the major growth constraints in acid soils that occupy up to 40% of global arable land, affecting 80 to 90 million hectares of the Australian agricultural area, including two-thirds (3.5 million hectares) of the WA wheatbelt. The estimated annual yield loss in acid soils prone to flooding and terminal drought would be 2.57 million tonnes of wheat, equivalent to $817 million.

We have shown genotypes with enhanced tolerance to individual ion toxicities (Fe, Al or Mn) have grain yield increased by at least 5% (a very conservative figure) in acid soils prone to flooding early in the season and also to drought later in the season

This project aimed to characterise tolerance to ion (Fe, Al, Mn) toxicities within Australian elite breeding lines and commercial wheat varieties.

A wide variation for tolerance to Fe, Al and Mn toxicity was observed within studied elite breeding lines and varieties. Information from this project will be used by: (i) growers, enabling them to make informed decisions on the selection of varieties suitable to their paddocks; and (ii) breeders, who will have improved knowledge about their varieties and advanced breeding lines.

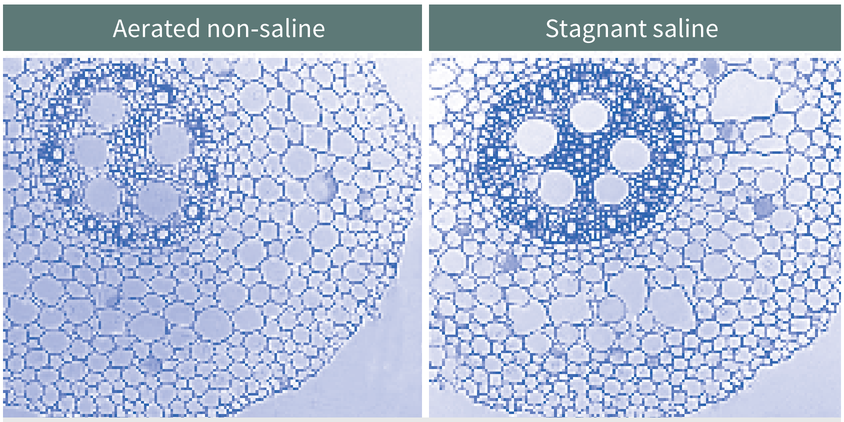
This research is funded by National Variety Trials (NVT) and GRDC.

Coping with flooding: nutrient transport in oxygen deprived roots

Project team: Prof Tim Colmer[1] (leader; email: timothy.colmer@uwa.edu.au), Dr Lukasz Kotula[1], Assoc/Prof Peta Clode[1], Prof Andre Lauchli[1], Prof Sergey Shabala[2], Prof Mikio Nakazono[3]

Collaborating organisations: [1]UWA; [2]University of Tasmania; [3]Nagoya University, Japan

Soil waterlogging decreases the availability of oxygen to roots. Impaired root growth and functioning results in nutrient deficiency in shoots of crops in waterlogged soils and contributes to reduced yields. Large areas of waterlogged agricultural land also suffer from salinity, and the combined effects of waterlogging and salinity can be especially damaging to crops. The focus of our experiments for this past year have been to evaluate



Comparison of barley root cells in aerated non-saline and stagnant saline environments

how oxygen availability and salinity affect potassium (K), sodium (Na) and chloride (Cl) accumulation in various cell types across the roots of barley (*Hordeum vulgare*).

Microelectrode tissue profiling has been used to determine the oxygen status of tissues across roots in aerated or stagnant (waterlogged) medium (IAS Visiting Professor Ole Pedersen from the University of Copenhagen assisted us with this technique when he visited UWA). Our results showed steep gradients for oxygen across roots with declines in the outer cell layers (epidermis/sub-epidermis) and within the stele (central cylinder). The severe oxygen deficiency which occurred within the stele and apical regions of roots in stagnant conditions would have resulted in low respiration and hence low energy supply – the likely cause for substantial changes in cellular ion concentrations – discussed below.

X-ray microanalysis was used to determine cell-specific localisation of K, Na and Cl in roots of barley plants from the various treatments. These measurements were conducted in collaboration with Assoc/Prof Peta Clode at the UWA Centre for Microscopy, Characterisation and Analysis. This study demonstrates that oxygen deficiency in roots had a significant impact on cellular distribution and concentrations of Na, Cl and K. An important finding was the changes in Na concentration profiles across roots in stagnant saline versus aerated saline conditions as these data highlighted that the ability of the roots to control radial Na transport was inhibited by low oxygen supply. When grown under aerated saline conditions, cells of the epidermis, sub-epidermis and outer cortex accumulated high amounts of Na, thereby helping to maintain a low Na concentration in the inner cells and in the xylem vessels within the stele of the roots. In contrast, relatively uniform and large concentrations of Na were observed across the entire roots of plants in stagnant saline conditions.

The severe oxygen deficiency that occurred in the stele of roots in stagnant conditions, as evidenced by microelectrode profiling, reduced the accumulation of K, Na and Cl in the pericycle and xylem parenchyma indicating that both of these cell types are involved in energy-dependant K loading into the xylem as well as in controlling radial Na and Cl transport. Thus, the combined use of the two techniques of oxygen microelectrode-profiling and X-ray microanalysis allowed us to characterise possible control points for ion transport in barley roots, both during exposure to salinity in aerated (i.e. drained) and oxygen-deficient (i.e. waterlogged) conditions.

Salinity tolerance requires the regulation of ion transport by roots to limit the rates of Na and Cl entry into the shoots. When salinity occurs together with soil waterlogging, rates of Na and Cl uptake increase, whereas K uptake decreases even further than when exposed to salinity alone. The present experiments have highlighted that oxygen deficiency adversely impacts on ion transport in various cell types of barley roots when in a stagnant saline environment. Even the relatively salt tolerant crop species of barley suffers greatly when exposed to both moderate salinity and waterlogging.

This research is funded by an ARC Discovery Project.

Organics–metals–salts interactions in food safety and environment protection: combined experimental and modelling approach

Project team: Assoc/Prof Gabrijel Ondrasek[2] (leader; email: gondrasek@agr.hr), Prof Zed Rengel[1], Prof Davor Romic[2], Assoc/Prof Peta Clode[1], Prof Matt Kilburn[1]

Collaborating organisations: [1]UWA; [2]University of Zagreb, Faculty of Agriculture, Zagreb, Croatia

This project deals with the current degradation processes in food-producing agro-ecosystems, namely metals contamination, salinisation and organic matter decline.

Metals contamination and increased salinity occur frequently and to a large extent in arid/semi-arid areas on predominantly light-textured soils low in organic matter. This project is aimed at characterising the benefits of various soil organic compounds in protecting crops and surface and groundwater from potentially toxic trace metals in salt-affected, metal-contaminated soils used for food production. Specific forms of metals detected in the crop rhizosphere by chemical fractionation and modelling by computational approaches will be related with metals visualised and quantified at the nano scale by state-of-the-art *in situ* microanalysis in plant tissues.

This research is funded by The European Commission, Research Executive Agency, Brussels/EU.

A pre-breeding and genetic diversity project in spring canola

Project team: Prof Wallace Cowling[1] (leader; email: wallace.cowling@uwa.edu.au)

Collaborating organisations: [1]UWA; Norddeutsche Pflanzenzucht Hans-Georg Lembke KG (NPZ-Lembke), Germany

A research team based in the IOA will develop a unique and valuable pre-breeding program for the global spring canola group in NPZ. NPZ Australia Pty Ltd funds this pre-breeding canola program at UWA to enhance genetic diversity and accelerate genetic improvement in elite germplasm.

Rapid cycles of recombination and selection will occur in two populations, namely 'Tripop' and 'Ozpop'. 'Tripop' combines elite parents from the Australian, Canadian and European spring canola programs in the NPZ group, and will be a source of great genetic diversity and variation in flowering phenology for selection in each of the global spring canola environments. 'Ozpop' will improve Australian-adapted elite germplasm, with increased genetic diversity and rates of recombination.

In 2014 selections were made in 'Tripop' for yield, blackleg resistance and seed quality. Superior inbred lines from the program were made available to the NPZ group and used in Australian hybrids. New hybrid and open pollinated canola varieties were licensed to Australian companies in 2014.

This research is funded through an ARC Linkage Project with support from COGGO and NPZ-Lembke.

The role of potassium to improve yield, growth and water use of drought-stressed canola

Project team: Mr Max Bergmann[1] (leader; email: bergmx@gmail.com), Dr Ken Flower[1], Hackett Prof Kadambot Siddique[1], Dr Craig Scanlan[2], Dr Andrew Guzzomi[1], Prof Klaus Dittert[3], Prof Andrea Carminati[3]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]University of Göttingen, Institute of Applied Plant Nutrition (IAPM), K+L Kali GmbH

Canola or oil seed rape (*Brassica napus*) is a major crop in various crop rotation systems around the world. Since the early 1990s it has been grown in WA in rotation with barley (*Hordeum vulgare*), spring wheat (*Triticum aestivum*) and lupin (*Lupinus angustifolius*). The grain belt region of WA has been traditionally classified as having a Mediterranean-type climate, characterised by hot, dry summers and cool, wet winters.

NPZ-Lembke visit to WA

Canola production in this region is vulnerable to large variations in rainfall and frequent droughts. Recent poor seasons and price volatility have contributed to farmers' perceptions of risk associated with canola to such an extent that the area sown to canola often declines after periods of drought. Nevertheless, the total area sown to canola in WA has increased over the past five years to 7.6% (0.56 million ha of the 18 million ha arable land) and the importance of the crop has become more apparent. In this variable climate it is clear that soil water is the most limiting factor for crop production, especially in low to medium rainfall regions. Hence, greater water use efficiency of canola would contribute to improved yields and crop reliability.

Currently about 8% of the WA cropping region is potassium (K) deficient. Furthermore, there is an increased risk that most of the sandy soils, which comprise 75% of the 18 million ha arable land in WA, will also become K deficient in the coming years due to leaching and the removal of K from soils with hay and grains. After nitrogen (N), K is the mineral element required in the largest quantities for optimal productivity and cropping, especially during the reproductive development phase of plants.

The general objective for this study was, therefore, to understand how K influences the drought tolerance of canola – in particular its effect on regulating stomatal conductance under water stress and how this may lead to higher growth and yield potential. The research question formulated was: 'Are plants well-supplied with K better able to regulate their stomata, maintaining a higher turgor pressure and rate of photosynthesis, leading to increased yields, compared with those with low or deficient levels of K?'

A high rate of K was found to reduce transpiration and stomatal conductance under drought stress leading to a reduction in relative turgor pressure and xylem potential in

Canola production in WA is vulnerable to large variations in rainfall and terminal drought

canola. Furthermore, a high K supply reduced the diurnal photosynthesis rate, stomatal conductance and transpiration during the afternoon, while the low K and no added K treatments increased photosynthetic activity over the course of the day.

Interestingly, a mild K deficiency caused a significantly higher rate of photosynthesis, stomatal conductance and transpiration under water-limiting conditions, implying that canola plants compensate for the deficiency by increasing the uptake of K. An interaction with the plant hormones ABA and ethylene may be a major factor contributing to the measured up-regulation in stomatal conductance for the no added K treatment. The high K treatment quickly recovered its relative turgor pressure compared with the no added K treatment. All drought-stressed samples over-compensated with regard to stomatal conductance, transpiration and photosynthesis during the recovery periods, only reaching their initial values at the beginning of the second drying cycle which suggests that the applied recovery phase was too short for a full recovery and that canola plants cannot be trained to withstand repetitive drought as they did not reduce their stomatal conductance to reduce water loss.

Canola develops a significantly larger root system under a mild K deficiency and drought stress. Furthermore, a higher than optimal rate of K had no significant effect on dry weight, leaf area or pod number as an indication for improved yield. Moreover, mild K deprivation only caused significant differences in growth if the duration of the deficiency was long enough.

This research is funded by GRDC and UWA.

Screening for drought tolerance in wheat: leaf osmotic potential is the key trait determining turgor loss point

Project team: Mr Kyle Mart[1] (leader; email: 20721283@studnet.uwa.edu.au), Prof Erik Veneklaas[1], Dr Helen Bramley[2]

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

Drought is the most significant constraint affecting Australia's wheat production. Higher seasonal variation due to climate change poses an increasing threat of warmer temperatures and lower rainfall which will further limit grain production. Development of new wheat cultivars is required to generate crops that can yield under water-limiting environments to combat further drought constraints. However, developing new cultivars is limited due to costly and time-consuming methods to screen for genetic variation of particular traits that infer drought tolerance.

This study investigated the genetic variation of osmotic potential at full turgor (π_o) among a range of glasshouse and field grown wheat cultivars to determine if π_o could be used as a selection criterion. The relationship of π_o and turgor loss point (Ψ_{tlp}) was also investigated to determine the potential of predicting Ψ_{tlp} of wheat using π_o under well-watered and drought conditions. Two methods for determining π_o were tested, namely pressure volume analysis and freeze-point osmometry, to examine if a more rapid and inexpensive approach could be used to measure π_o and predict Ψ_{tlp}.

Significant genetic variation of π_o was determined among a range of 39 field grown cultivars and eight glasshouse grown genotypes ($p < 0.01$). A significant relationship between the π_o and Ψ_{tlp} was determined under well-watered conditions ($r = 0.84$) and under drought conditions ($r = 0.72$). Significant contrast in whole-plant transpiration and stomatal conductance elucidated unique responses underlying turgor maintenance in different genotypes. Overall, there is potential for researchers and breeders to gain access to a rapid, inexpensive and reliable method to measure physiological relationships that govern tolerance to water-limiting conditions. The π_o has potential to be utilised as a drought tolerance indicator among a large number of genotypes.

This research is funded by UWA and GRDC.

Unleashing the power of genomics for lupin marker development and crop improvement

Project team: Assoc/Prof Matthew Nelson[1] (leader; email: matthew.nelson@uwa.edu.au), Dr Aneeta Pradhan[1], Candy Taylor[1], Naghmeh Besharat[1], Prof Willie Erskine[1], Dr Ricarda Jost[1], Dr Jens Berger[2], Prof Karam Singh[1,2], Christiane Ludwig[2], Dr Lars Kamphuis[2], Dr James Hane[3]

Collaborating organisations: [1]UWA; [2]CSIRO; [3]Department of Environment and Agriculture/ Curtin University

Narrow-leafed lupin (*Lupinus angustifolius*) or NLL is a young crop species, having been domesticated in the latter half of the twentieth century. Previous research revealed the low genetic and phenological diversity in Australian varieties.

Genetic variation of osmotic potential at full turgor in wheat was investigated

This project aims to understand this diversity and to develop molecular markers to help broaden diversity in Australian varieties.

The genetic and ecophysiological control of flowering time in NLL is being investigated by growing diverse accessions and a reference mapping population in contrasting conditions in controlled environmental conditions. This is uncovering the relative importance of vernalisation (cold treatment associated with winter), day-length and ambient temperature in the time of flowering in NLL and how these environmental factors interact with genes.

In collaboration with the UWA–CSIRO lupin genome sequencing project, 480 SNP marker assays were developed and used to map the NLL genome. The markers were also used to understand genetic relationships among 250 wild accessions and domesticated lines from Europe and Australia.

The expression of a candidate gene for the main flowering time locus in NLL (*Ku*, controlling vernalisation response) was characterised using quantitative polymerase chain reaction (PCR). It was found that expression of this candidate gene correlates closely with response to vernalisation, further strengthening the gathering evidence that this is the gene underlying the *Ku* locus.

This research is funded by GRDC.

Assoc/Prof Matthew Nelson examining canola phenology in the field

What controls the variation in flowering time in canola varieties?

Project team: Assoc/Prof Matthew Nelson[1] (leader; email: matthew.nelson@uwa.edu.au), Prof Wallace Cowling[1], Prof Ravikesavan Rajasekaran[2], Dr Alison Smith[3], Dr Sheng Chen[1], Adj/Prof Cameron Beeck[1], Hackett Prof Kadambot Siddique[1]

Collaborating organisations: [1]UWA; [2]Tamil Nadu Agricultural University (India); [3]University of Wollongong

Time of flowering is a key adaptive trait in plants and is conditioned by the interaction of genes and environmental cues including length of photoperiod, ambient temperature and vernalisation. Here we investigated the effect of photoperiod on the flowering time of summer annual types of *Brassica napus* (rapeseed, canola) using a doubled haploid population derived from a cross between European and Australian parents. The parents were homozygous lines derived by microspore culture of the European high oleic, low linolenic variety Lynx and the Australian conventional canola variety, Monty. The population, along with parental and variety controls, was evaluated for days to flowering, thermal time to flowering (measured in degree-days) and the number of leaf nodes at flowering in a compact and efficient glasshouse-based experiment with replicated short- and long-day treatments. All three traits were under strong genetic control with heritability estimates ranging from 0.85 to 0.93.

There was a very strong photoperiod effect with flowering in the population accelerated on average 765 degree-days in the long-day versus short-day treatments. However, there was a strong genetic correlation of line effects (0.91) between the long- and short-day treatments and relatively low genotype x treatment interaction, indicating that photoperiod had a similar effect across the population. Bivariate analysis of thermal time to flowering in short and long days revealed three main effect quantitative trait loci (QTLs) that accounted for 57.7% of the variation in the population and no significant interaction QTLs. These results provided insight into the contrasting adaptations of Australian and European varieties. Both parents responded to photoperiod and their alleles shifted the population to earlier flowering under long days. Wide transgressive segregation in thermal time to flowering showed the wealth of genetic variation available to canola breeders if they cross between Australian and European breeding pools. Potential candidate flowering time homologues located near QTLs were identified with the aid of the *B. rapa* and *B. oleracea* reference genome sequences. These findings will help guide the breeding of canola varieties that are adapted to new and changing environments.

This research is funded by ARC, NPZ, Germany, and COGGO.

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

Project team: Prof Martin Barbetti[1] (leader; email: martin.barbetti@uwa.edu.au), Ms Niroshini Gunasinghe[1], Dr Ming Pei You[1], Surinder S. Banga[2], Shashi K. Banga[2], Prabhjot S. Sandhu[2], Huang Yi[3]

Collaborating organisations: [1]UWA; [2]Punjab Agricultural University, India; [3]Chinese Academy of Agricultural Sciences, China

White leaf spot, caused by the fungus *Pseudocercosporella capsellae*, is a serious disease across oilseed and vegetable *Brassica* growing regions worldwide, including Australia. Effective host resistance is urgently needed if white leaf spot is to be economically managed.

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

At the Crawley field site, *B. carinata* ATC 94129 was the most highly resistant genotype, followed by *Crambe abyssinica*, *Eruca sativa* Eruc-01 and *E. vesicaria* (yellow rocket). B. *carinata* ATC 94129 and *B. oleracea* var. *capitata* showed almost no leaf collapse compared with massive leaf collapse on highly susceptible genotypes.

At the Shenton Park field site, 21 genotypes of *B. carinata* and *B. oleracea* var. *acephala* (Tuscan kale) showed total resistance to white leaf spot.

Within both *B. napus* and *B. juncea* genotypes tested, the most resistant genotypes were from China and the most susceptible from India, with those from Australia being intermediate.

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

This research is funded by GRDC.

Typical White leaf spot symptoms on foliage of mustard

Assessing the role of transpiration in ameliorating leaf temperature in wheat (*Triticum aestivum*)

Project team: Ms Chandima Ranawana[1] (leader; email: chandima.ranawana@research.uwa.edu.au), Hackett Prof Kadambot Siddique[1], Adjunct Prof Jairo A. Palta[1,2], Dr Helen Bramley[3]

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

Wheat is an important crop in Australia and is mostly grown under rain-fed conditions. High temperature and drought stress, which often occur simultaneously, are considered the most critical environmental variables that can lead to a drastic yield reduction in wheat. Therefore breeding and agronomic strategies that minimise the impact of high temperature on wheat growth and development need to be explored. The canopy temperature of a crop can be several degrees cooler than the air temperature due to evaporative cooling during transpiration. Therefore transpiration is an important mode of temperature regulation in plants. However, the relationship between leaf/canopy temperature, air temperature and transpiration is complex due to its relationship with the physical environment and plant anatomical and morphophysiological attributes. We aim to unravel the above complex relationship through comprehensive examination of transpiration and leaf cooling under varying levels of its controlling factors such as vapour pressure deficit (VPD), air temperature and soil moisture availability.

A controlled environment study conducted during 2013 under two watering regimes (well-watered and water-stressed) using eight wheat genotypes with varying morphophysiological attributes and responses to heat and drought yielded some interesting results. It was found that there is a genotypic variation in transpiration response to VPD where some genotypes transpired continuously while others restricted their transpiration after a certain VPD threshold. Also, the leaf temperature was found to be affected by those varied transpiration responses to VPD. However, in some genotypes, leaf temperature did not correlate with transpiration response.

In 2014 two genotypes with contrasting transpiration response to VPD (from the 2013 results) were identified and further experimented under controlled steady state conditions to identify the physiological basis for the existence of varied transpiration responses to VPD. We expected that those contrasting responses would be mediated by plant hydraulic restrictions which may be differently expressed between genotypes. Roots were held constant at two temperature regimes, 22 °C (control) and 4 °C (restricted root hydraulic conductivity) and shoots were gradually exposed to four VPD levels. Preliminary data analysis showed an existence of differential root and shoot hydraulic restrictions among genotypes and between watering regimes. Detailed analysis is being carried out.

This research is funded by an Endeavour Postgraduate Research Award and UWA.

Developing molecular markers for tedera, an emerging pasture legume for low rainfall regions of Australia

Project team: Assoc/Prof Matthew Nelson[1] (leader; email: matthew.nelson@uwa.edu.au), Dr Daniel Real[2], Dr Aneeta Pradhan[1], Naghmeh Besharat[1], Dr Maria Pazos-Navarro[1], Dr Marie-Claire Castello[1], Dr Janine Croser[1], Dr Jafar Jabbari[3]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]Australian Genome Research Facility

Tedera (*Bituminaria bituminosa* vars. *albomarginata* and *crassiuscula*) is a traditional perennial forage legume of the Canary Islands, Spain. Its high forage quality and productivity over the summer season led to the establishment of a tedera breeding program at DAFWA. In this project we are developing molecular markers to address basic breeding issues relating to cross pollination in control and field conditions, for understanding genetic diversity and for facilitating transfer of genomic information from its richly resourced relative, soybean.

This year we demonstrated that cross pollination occurs in tedera grown in field conditions, likely assisted by bees. We found that crossing occurs freely across botanical varieties. This information allowed the breeding program to identify an effective approach for cultivar development.

In current work, we are developing the first map of the tedera genome, and indeed the first such map for any member of the Psoraleeae tribe of legumes. Preliminary genotyping-by-sequencing results indicate that large tracts of the tedera genome maintain the same structure as the soybean genome, which will aid transfer of information from the soybean model system to tedera.

This research is funded by Future Farm Industries CRC.

Assessing the role of transpiration in ameliorating leaf temperature in wheat

Genomic basis of clonal variation in Cabernet Sauvignon wine grapes

Project team: Dr Michael Considine[1] (leader; email: michael.considine@uwa.edu.au), Prof Ryan Lister[1], Prof James Whelan[6], Mr Glynn Ward[2], Ms Kristen Brodison[2], Mr James Campbell-Clause[3]; Mr Daniel Newson[4], Dr Paul Chambers[5]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]WA Vine Improvement Association; [4]Yalumba Wines; [5]Australian Wine Research Institution; [6]La Trobe University

A 'clone' is a horticultural term that refers to propagation of cuttings, rather than sexual propagation, perpetuating the specific qualities of the mother plant. It is an economically essential practice for perennial tree crops. Put simply, a clone is a sub-sub-species. However, the classification is limited to physical quality attributes, rather than genetic variation. Hence the confidence of classification is poor, undermining confidence of the stable expression of desired traits. Potential underlying causes are many: (i) DNA mutation affecting the whole plant genome; (ii) DNA mutation affecting

Cabernet Sauvignon wine grapes

only one lineage of cells (chimera); (iii) influence of virus infection on the host genome; and (iv) epigenetic variation; or (v) combinations of each of these.

The project agreement was signed and the project commenced in February 2014. An industry forum was held in Margaret River in October, affirming project priorities, namely to dissect the genomic basis of clonal variation in grapevine, using Cabernet Sauvignon as the pilot due to the value of this variety to the WA and Australian wine economies. Secondary priorities centred on technologies to map the identities of commercial populations (vineyards) and technologies for targeted vine improvement for high quality Australian wine production.

Goal 1 was to sequence the entire genome of approximately 12 economically important clones from WA and SA vine populations. Genetic material was collected from 10 clones plus stock/scion combinations of four of those clones, in WA or SA in November 2014. These will be sequenced using next-generation sequencing technology. Goal 2 will be to extend research beyond the DNA code to decipher the underlying causes of clonal variation.

A postdoctoral position for the genome research was advertised in July 2014 and a candidate was appointed in August. Dr Patricia Agudelo-Romero comes with exceptional experience in genome technologies specifically applied to grapevine. She will commence in April 2015, and will commence genome sequencing after training in the specific platforms at the ARC Centre of Excellence in Plant Energy Biology, UWA.

This research is funded by an ARC Linkage Project.

Improved food crop varieties for Timor-Leste

Seeds of Life III

Project team: Prof William Erskine[1] (leader; email: william.erskine@uwa.edu.au), Adj/Prof Harold Nesbit[1], Hackett Prof Kadambot Siddique[1], Adj. Senior Research Fellow Rob Williams[1]

Collaborating organisations: [1] UWA; Department of Foreign Affairs and Trade (DFAT); Timor-Leste Ministry of Agriculture and Fisheries

The Seeds of Life (SoL) program in Timor-Leste continues 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 aims to introduce improved crops to more than 50% 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 ACIAR and 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 the Centre for Legumes in Mediterranean Agriculture (CLIMA)-PGB. SoL3 has components of research, seed multiplication, community seed development and capacity building.

The research program 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 trials being conducted on winged bean, mung bean and other legumes. Pro-vitamin enriched maize varieties and other nutrient enhanced crops are also being examined.

The focus is now on developing the national seed system to ensure widespread dissemination of the new highly promising varieties. Seed of the popular yellow maize (Sele) and the newly-released Noi Mutin or 'Little Princess' maize, peanut (Utamua) and rice (Nakroma) were multiplied by Government and non-governmental organisations (NGOs), seed producers, community seed production groups and individual farmers for cultivation or sale. Sweet potato (Hohrae 1, 2 and 3) and cassava (Ai-Luka 2 and Ai-Luka 4) cuttings were also multiplied in small plots in each district for sale to farmers.

Our 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 1000 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, piggybacking 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 24.6% of all rural households in the country. By 2014 this adoption rate had risen to 32.5% of interviewed farmers growing one or more of the new released varieties. The target is to reach 50% of the households by mid-2016.

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 to support the seed system in the future. The program is currently supporting five MAF staff with their Masters studies (two in Indonesia and three at UWA).

This project is funded by ACIAR and DFAT.

Farm management

Long-term no-till farming systems

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

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

The aim of this trial was to determine the long-term effect of a high residue, no-tillage system on soil quality, soil water balance, insects, diseases, weeds and crop residue dynamics as well as crop growth, yield and profitability. The main hypotheses are that high crop residue levels will outperform low levels in no-tillage cropping systems (e.g. higher soil organic carbon, increased soil water storage/infiltration, higher yields) and that the most diverse rotation will have less weed, disease and insect pests and increased wheat yields compared to cereal monoculture.

Surprisingly, after seven years, wheat yield in a monoculture was similar to that grown in a more diverse rotation. Very high levels of crop residue present at seeding (about 5 t ha-1 residue) appeared to decrease crop yields compared with low levels (< about 2 t ha-1 residue), whereas moderate levels of residue (about 3 t ha-1 residue) had higher yields than the low levels of residue (< about 2 t ha-1 residue). Overall, the highest gross margin from 2007 to 2012 occurred with continuous wheat, while the most variable was the diverse rotation which included legumes and canola. Low overall gross margin with this rotation occurred when the brassica (canola) phase coincided with dry conditions and the legume with the good/wet conditions, because of low returns from the legume in high potential years. Conversely, this rotation had the highest gross margin when the canola was grown in a good year and the legume in the drought years. The wheat gross margin was less sensitive to rainfall or seasonal variability.

This project is funded by GRDC.

WANTFA demonstration

Mr Araz Abdulla investigates the use of film-forming antitranspirants to reduce the impact of drought on wheat yield.

Use of film-forming antitranspirants to reduce the impact of drought on wheat yield

Project team: Mr Araz Sedqi Abdulla[1] (leader; email: 21061607@student.uwa.edu.au), Dr Ken Flower[1], Hackett Prof Kadambot Siddique[1]

Collaborating organisations: [1]UWA

This research formed part of an MSc project. The objectives were: (i) to investigate the potential of film-type antitranspirants to reduce transpiration and alleviate adverse effects of late-season drought on wheat growth and yield; and (ii) to examine the hydration status of wheat plants subjected to water deficit and film antitranspirant applications by providing real time leaf turgor measurements.

Gglasshouse research showed that water stress reduced wheat yield by 40% compared with a well-watered control. However, the yield loss of these water stressed plants was only 15% less than the controls when sprayed with an antitranspirant at the booting stage. Antitranspirants therefore have potential to reduce yield losses from late-season drought stress.

This project is funded by GRDC.

Does ABA-mediated stomatal regulation in wheat genotypes result in better yield performance under terminal drought?

Project team: Ms Renu Saradadevi[1] (leader; email: renu.saradadevi@research.uwa.edu.au), Hackett Prof Kadambot Siddique[1], Adjunct Prof Jairo A. Palta[1,2], Dr Helen Bramley[3]

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

Farming systems in the Mediterranean climatic system of Australia are affected by terminal drought due to decreasing rainfall and rapid rise in temperature. Terminal drought or end-of-season drought, which is the drought during anthesis and grain developmental stages, is considered the most significant stress affecting wheat yield. This research is evaluating wheat genotypes to identify those with efficient stomatal mechanisms to limit water loss and conserve water to prolong the water availability for the grain-filling period, thus reducing yield gap under terminal drought. The research aims to generate information relevant to wheat physiology and breeding strategies for the development of future water efficient wheat cultivars.

Two drought tolerant released wheat cultivars (Drysdale and Wyalkatchem) and two advanced breeding lines (IGW-3262 and IGW-3119) were grown in split pots to identify two contrasting genotypes in terms of their stomatal response to terminal drought stress. The genotypes were observed to differ in their early stomatal response and the accumulation of abscisic acid in their leaves when one half of their root system was exposed to soil dryness. The two most contrasting genotypes, Drysdale and IGW-3262, were then grown in segmented pots to identify the role of root distribution in the signal generation and subsequent stomatal closure. When the top pot segment was exposed to drought while water

Two drought tolerant wheat cultivars (Drysdale and Wyalkatchem) and two advanced breeding lines (IGW-3262 and IGW-3119) grown in split pots was available in the bottom segment, Drysdale with more root biomass distribution in the top drying soil layer initiated stomatal regulation earlier. Drysdale was also found to have better yield while IGW-3262 did not show any yield benefit when water was available in the bottom segment.

In 2014 the focus of the study was to identify if the observed yield variation between Drysdale and IGW-3262, identified to have contrasting stomatal response to terminal drought, was due to the difference in their post-anthesis water use. The wheat plants were grown in pots of 0.15cm diameter and 1m long. Terminal drought was initiated by withholding water from the pots at anthesis. In one set of terminal drought initiated pots, the bottom one-third of the soil column was maintained at its water holding capacity by injecting water through irrigation tubes. Preliminary analysis shows that the genotypes differ in their capability to extract water from depth and the observed yield benefit in Drysdale is due to its greater post-anthesis water use.

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

The use of supplementary feed in a wheat crop to improve uniformity of sheep grazing

Project team: Ms Benita Moir[1] (leader; email: 20501394@student.uwa.edu.au), Dr Ken Flower[1], Dr Dean Thomas[2]

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

This research was done as part of an honours research project. The objective was to improve the uniformity of crop grazing by attracting sheep from over- to under-utilised areas of a wheat crop with the use of a mineral supplement.

Two paddocks of wheat on a farm in the WA central wheatbelt area of Tammin were grazed for two weeks without supplement. Following this, plots of high, medium and low grazing intensity were selected, based on sheep movements and grazing which were monitored with GPS tracking devices on the sheep. A mineral supplement was placed in half of the plots identified as low grazing intensity. Sheep were then re-introduced and the paddocks grazed for another two weeks to determine if the supplement altered their grazing pattern. Crop biomass cuts and visual grazing score measurements were also taken throughout the experiment to support the GPS data. There was less grazing in the plots which had previously been heavily grazed, with a significant increase in the low grazing intensity plots. Overall there was no significant difference in grazing intensity between treatment plots after the supplement was introduced, indicating that grazing distribution became more uniform as a result of the supplement.

This project is funded by UWA.

Phosphorus-efficient legume pasture systems (UWA module)

Project team: Dr Richard Simpson[1,2] (leader; email: Richard.simpson@csiro.au), Assoc/Prof Megan Ryan[1], Mr Graeme Sandral[3], Dr Richard Culvenor[2], Prof Hans Lambers[1], Dr Phillip Nichols[1,4], Mr Richard Hayes[3], Mr Robert Jeffery[1] (PhD student), Prof Martin Barbetti[1]

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

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 approximately 10,000 available accessions.


Assessing the growth and root traits of subterranean clover growing in 11 field soils

This project aimed to: (i) prove that highly productive pasture systems can be operated with substantially less P fertiliser by using plants with low 'critical' P requirements;.(ii) quantify (benchmark) the critical P requirements of key pasture legume species relative to subterranean clover; (iii) identify the root morphology traits that have the largest influence on the critical P requirements of subterranean clover and alternative legume species; (iv) assess the variation in P-efficient root traits of subterranean clover and quantify the potential for breeding P-efficient clovers; (v) develop a clear decision point for breeding improved subterranean clovers, and/or evaluating alternative legume species for P-efficient farming systems; and (vi) 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 (the project's home), NSW-DPI, Wagga Wagga, and UWA. At UWA in 2014 a large range of alternative pasture legumes (and some grasses) were grown in the glasshouse, along with subterranean clover and other current pasture species, and rhizosphere carboxylate (organic anion) concentrations and composition were assessed. Root traits were also evaluated (e.g. specific root length, average root diameter and average root hair length). Assistance was also supplied to the Southern Dirt Farmers Group to undertake related field experiments. UWA PhD student, Robert Jeffery, completed two experiments which examined the growth and P uptake of three subterranean clover cultivars grown as micro-swards under six levels of P addition, both with and without the pathogen *Pythium irregulare*. The aim was to see if the response to P differed when roots were infected with this pathogen.

This project is funded by MLA and AWI.

Michael Renton and Maggie Triska

Modelling/crop sequence strategies and tactics

Design and evaluation of biosecurity surveillance systems 1

Project team: Assoc/Prof Michael Renton[1] (leader: michael.renton@uwa.edu.au), Dr Remi Crete[1], Prof Martin Barbetti[1], Dr Moin Salam[2]

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

Phoma stem canker or blackleg, caused by the fungus *Leptosphaeria maculans*, is one of the most damaging diseases of oilseed rape that exists wherever canola is present. 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. The disease is more severe in areas of intensive canola production.

Fungal spores are released from canola stubble and spread extensively via wind and rain splash. Control strategies rely on fungicides, deep tillage of the crop residues, use of resistant cultivars and crop management (specific sowing period, crop rotations). Using resistant cultivars is the most effective and commonly used method in Australia, but 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 pathogenic variants of the pathogen and reduce pathogen population sizes.

We aimed to explore under what conditions different strategies will lead to the emergence of super virulent strains, given the limited available space for infection and the resulting competition between strains. We built a new model specifically to address these issues and, more specifically, we used it to address the following questions: How do initial levels of pathogen, with different proportions of the different strains, affect the selection of a very virulent strain when rotating cultivars? How can the evolution of super-strains be avoided or delayed by adapting the cultivar or crop rotation?

We tried two different scenarios of rotation of four cultivars, each with one major gene of resistance, changing cultivar every year or changing every five years. We considered different initial amounts of inoculum and different proportions of virulent alleles. We found that rotation of cultivars looked more effective (for these examples) with annual rotation than with five-yearly rotations and that, in case of high initial levels of virulent inoculum, rotating canola with another crop unaffected by blackleg appeared to be necessary.

We will now move on to study spatial interactions between fields and model more accurately genetic interaction between strains and cultivars (polygenic resistance, first contact effect), taking into account mutations and genetic drift.

This project is funded by GRDC.

Design and evaluation of biosecurity surveillance systems 2

Project team: Assoc/Prof Michael Renton[1] (leader; email: michael.renton@uwa.edu.au), Prof Benedict White[1], Dr Jackie Edwards[3], Dr John Wainer[3], Dr Maggie Triska[1], Dr John Botha[2], Dr Cassandra Collins[4], Dr John Weiss[3], Prof Roger Jones[1], Mr Andrew Taylor[2], Dr Lloyd Stringer[5], Dr Sarah Collins[2], Dr Sonya Broughton[2], Assoc/Prof Kevin Powell[3]

Collaborating organisations: This is part of a national project including [1]UWA; [2]DAFWA; [3]NSW-DPI; [4]University of Adelaide; [5]New Zealand Plant and Food Research Limited (PRFNZ); Phylloxera and Grape Industry Board of South Australia (PGIBSA)

We assessed the influence of dispersal kernels with and without long-distance dispersal (LDD) events on the optimal method of surveillance for hypogeic crop pests. Crop pests can cause economic loss by reducing crop yields and restricting domestic and international trade. In Australia crop pests, specifically insects and mites, result in an estimated loss of US$ 2.6 billion per year and, as these pests spread, economic losses will increase. Therefore, to limit economic loss, early detection of crop pests in new areas is essential. Early detection requires optimal methods of surveillance to detect pests quickly. Optimal methods of surveillance are influenced by the ability of a pest to spread, which is likely dependent on their dispersal potential.

The dispersal of most pests includes sporadic LDD events which have the potential to increase their dispersal from a few metres to kilometres. These LDD events occur through vectors including humans (i.e. via the movement of equipment or soil), water or wind. As dispersal through LDD events is more common than constant uniform dispersal in pests, we designed a spread model to assess if the time to first detection was dependent on the surveillance methods deployed. Specifically, we simulated the dispersal of four generic pests, three with Weibull dispersal kernels and LDD events of up to 5, 10 and 20km, and one with an exponential dispersal kernel, in a farm with 25 fields (1 ha each). Next, to assess the influence of dispersal kernel on surveillance method, the output from the spread model was overlaid with surveillance points. The surveillance points ranged from 1 point/2 fields to 25 points/1 field in either a grid or random arrangement within the fields.

Overall, the mean time to detection (over 100 replicates for each dispersal type) was lowest for pests with Weibull dispersal kernels and LDD events, compared to the pest with exponential dispersal kernels. However, at the time of detection, pests with Weibull dispersal kernels and LDD events were able to spread further, infest more fields and had a greater population size than the pest with an exponential dispersal kernel. These results suggest that modelling pests with a constant dispersal without LDD events may underestimate the pests' total spread and population size at the time of detection, and overestimate the potential to control or eradicate the pest.

Next we will adapt the spread model to identify optimal strategies of surveillance for three case studies. These case studies include two arthropod pests, grape phylloxera (*Daktulosphaira vitifoliae*) and Mediterranean fruit fly (*Ceratitis capitata*) and one nematode pest, potato cyst nematode (*Globodera rostochiensis*). Currently, to improve surveillance for these pests, expert opinion and additional information are being collected from collaborators to design pest specific models that mimic real-word conditions and surveillance strategies.

This project is funded by Plant Biosecurity CRC.

Modelling spatial and temporal dynamics of rhizosphere exudation

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

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

The plant availability of phosphorus (P) is limited to a large extent by the rate of reactions that replenish the pool of soluble P. The biology of P uptake by roots is relatively well-known, with root exudation of organic compounds, mycorrhiza and specialised cluster roots being important for P acquisition, especially in habitats with low P availability. Narrow-leafed lupin (*Lupinus angustifolius*) is an important component of sustainable farming systems in the Mediterranean-type climatic region. It is the predominant grain legume crop in southern Australia due to its general phenological adaptation to Mediterranean-type environments. Narrow-leafed lupin does not form cluster roots, nor does it develop effective mycorrhizal association; hence, this species has developed other adaptive strategies critical for P uptake, such as increased exudation of organic acid anions (carboxylates) and alteration of the root architecture. 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 aluminium, iron and calcium. Thus they may help release phosphate from inorganic phases by ligand exchange or ligand-enhanced dissolution.

The aims of this project are to:
(i) 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 P by crops growing in heterogeneous soils; and
(ii) 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 by incorporating the knowledge of compounds and processes governing root exudation and crop capacity to capture P from heterogeneous soils.

Dr Yinglong Chen extracts rhizosphere exudations from individual lupin plant root tips

Research activities in 2014 were focused on examining root responses in structure and physiology (such as rhizosphere exudation). Major accomplishments include: (i) investigation of the effect of P deficiency on root growth, root density and distribution in soil profile, and dynamics of rhizosphere exudations using anion exchange membranes (non-destructive sampling); and (ii) examination of the influence of localised P supply on root distribution and exudations using root washing (destructive sampling). The experiments compared variation in carboxylate exudation at spatial (taproot and lateral roots at various depths) and temporal (various plant growth stages) levels, and at species/genotype levels. The rhizotron system used in both experiments contained a removable clear panel which enables visualisation of root growth with time. Lactate, acetate, maleate, fumarate and citrate were commonly present in the rhizosphere of tested lupin species and genotypes, while trace amounts of malonate, cis-aconitate, succinate and trans-aconitate were detected in some samples. There were significant differences ($P<0.01$) in detectable carboxylate species among genotypes (two wild genotypes and two cultivars), and among root tips (except for lactate). The P-efficient genotype exuded significantly higher concentrations of lactate, acetate and fumarate than the inefficient genotype, while the inefficient genotype exuded about a threefold higher concentration of maleate than the efficient one. Data for exudation, plant P acquisition and soil P distribution will be used to parameterise the ROOTMAP model for the purpose of modelling spatial and temporal dynamics of exudation in response to low P supply.

This project is funded by an ARC Discovery Project.

Modelling the evolution of herbicide resistance with individual genetic based computer simulations

Project team: Ms Gayle Somerville[1] (leader: email: gayle.somerville@research.uwa.edu.au), Assoc/Prof Michael Renton[1], Prof Stephen Powles[1,2]

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

The herbicide resistant weed ryegrass flourishing in an annual winter wheat crop. Photo by A. Storrie.

Resistance to herbicides used on cropping weeds is a serious issue facing today's farming industry. Agronomic changes to continuous cropping and minimum tillage farming systems have meant an increased reliance on herbicides to control weeds, resulting in more evolutionary pressure towards resistant plants.

Through these studies we aim to increase our understanding of the differences in the rate of evolutionary pressure applied by different farming practices and different herbicides, and use this information to improve recommendations on best practices to delay the evolution of herbicide resistance.

In 2014 the focus of the research was on why the evolution of resistance to different groups of herbicides is variable, as definitive reasons for these between-group differences are not yet established.

There are many possible reasons for differences in the evolutionary rate of resistance between different herbicides. Questions exist over initial allele frequency, cross-resistance and the genetic basis of resistance within tested populations of weeds; additionally, unknown biological variability between populations can also limit reliability in weeds research. Modelling allows us to remove both between-herbicide and between-population variability, leaving only the desired between-group differences. Then via simulation we can quickly explore how these targeted differences influence herbicide resistance evolution over several years of cropping.

Two herbicide groups generating large differences in the rate of resistance evolution are firstly the group targeting the biosynthesis of very-long-chain fatty acids (VLCFA-inhibiting) group and secondly those affecting acetohydroxy acid production (AHAS-inhibiting) herbicides. The most common VLCFA-inhibiting herbicide is a chemical called trifluralin, a pre-emergent residual herbicide released in the 1960s. Trifluralin can give good control where soil contact is assured. However, high crop residue levels in minimum till agriculture and a decline in efficiency with delayed weed germinations can lower trifluralin kill rates. A widely used ALS inhibitor herbicide was Glean®, the first sulfonylurea brought out by DuPont in the early 1980s. Glean® contains chlorosulfuron, a systemic in-crop herbicide that acts on weeds which are actively growing at the time of application. Many AHAS-inhibiting herbicides, including Glean®, lost favour due to the development of herbicide resistant weeds within a few years of initial use. This is in contrast to the VLCFA-inhibiting pre-emergent herbicides that remained effective for many years.

Compared to the earlier released trifluralin these ALS-inhibitor selective herbicides were effective at much lower doses and were much safer for humans and other animals. This, along with the greater efficacy and earlier sowing dates allowed with the use of in-crop herbicides, meant that they quickly became more popular than trifluralin for the control of annual weeds in minimum till cereal crops. The reduced effectiveness of trifluralin on later cohorts is often due to photodecomposition and volatilisation. Single dominant gene resistance to these two herbicide groups is common.

The purpose of this year's work was to isolate and then examine the effects of herbicide application time and cohorts of weed killed from the influences of herbicide kill rate and initial allele frequency on the evolution of herbicide resistance. The two farming scenarios generated were based on the use of a pre-emergent VLCFA-inhibiting or an in-crop post emergent AHAS-inhibiting herbicide. We found that evolution of a single dominant gene for resistance to the pre-emergent herbicide occurred at a slower rate than for the in-crop herbicide, although this single difference was insufficient to extend the pre-emergent's effective use period compared to the in-crop herbicide.

This project is funded by UWA.

Flavonoid-rich foods and human health

Project team: Res/Prof Jonathan Hodgson[1] (leader; email: jonathan.hodgson@uwa.edu.au), Prof Kevin Croft[1], Asst/Prof Michael Considine[1], Dr Catherine Bondonno[1], Prof Richard Prince[1], Assoc/Prof Richard Woodman[2], Prof Ian Puddey[1], Dr Natalie Ward[1], Ms Lisa Rich[1], Dr Kerry Ivey[1], Dr Joshua Lewis[1], Ms Nicola Bondonno[1], Ms Diana Fisher[3]

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

Polyphenols are currently among the phytochemicals being actively studied as potential candidates for the cardioprotective effect of a fruit and vegetable rich diet. Polyphenols are produced as secondary plant metabolites and comprise two main classes: flavonoids and phenolic acids. While more than 8000 polyphenols have been identified, evidence suggests that intake of certain subclasses and specific flavonoids may be more important to human health than total intake. Quercetin, in particular, could be a key player in the cardioprotective effects mediated by flavonoids. A primary dietary source of quercetin is apples.

While flavonoids are antioxidants *in vitro*, it is their effects on nitric oxide that could be the basis for their health benefits. Nitric oxide is a key molecule in vascular health. We have previously demonstrated an acute improvement in vascular function through effects on nitric oxide after flavonoid-rich apple intake in healthy volunteers. The flavonoid-rich apples were high in quercetin. Laboratory and animal studies we have conducted have confirmed that quercetin has beneficial effects on vascular function though the effects on nitric oxide.

Apples are rich in flavanoids

As part of this project, a randomised controlled trial is currently underway investigating the dose response of pure quercetin on vascular function in healthy human volunteers, and in a separate study we are investigating if a four-week consumption of flavonoid-rich apples will lower blood pressure and improve vascular function in volunteers at increased risk for cardiovascular disease. Additionally, we have evaluated and are continuing to evaluate and quantify four important flavonoids with potential health benefits, including quercetin, in over 20 Australian apple identities (eight breeding accessions and 13 commercial varieties).

This project is funded by NHMRC, ARC Linkage, DAFWA, Horticulture Australia Ltd and Fruit West.

The importance of nitrate-rich vegetables for vascular health in humans

Project team: Res/Prof Jonathan Hodgson[1] (leader; email: jonathan.hodgson@uwa.edu.au), Prof Kevin Croft[1], Dr Catherine Bondonno[1], Prof Richard Prince[1], Assoc/Prof Richard Woodman[2], Prof Ian Puddey[1], Dr Natalie Ward[1], Mr Alex Liu[1], Ms Lisa Rich[1]

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

Diets high in fruit and vegetables, in particular green leafy vegetables, are associated with a decrease in risk of cardiovascular disease. Green leafy vegetables such as lettuce, rocket and spinach are rich in dietary nitrate. Recent evidence suggests that dietary nitrate may be a cardioprotective component of a vegetable-rich diet.

Dietary nitrate, through an enterosalivary pathway, is sequentially reduced to nitrite and nitric oxide. Nitric oxide has a number of critical functions in cardiovascular health including relaxation of blood vessels and regulation of blood pressure. We have previously demonstrated that nitrate supplementation can cause a dose-dependent increase in markers of nitric oxide metabolism and that ingestion of nitrate-rich vegetables can reduce arterial stiffness and blood pressure in healthy volunteers.

Recent trials undertaken as part of this project have shown that inhibition of nitrate reduction through the enterosalivary pathway by use of antibacterial mouthwash results in higher blood pressure in treated hypertensive individuals. We also demonstrated that increasing dietary nitrate for seven days may not be an effective short-term strategy to lower blood pressure in individuals with high-normal blood pressure or those with treated hypertension. Studies are currently underway to investigate if increased daily consumption of nitrate-rich vegetables for four weeks will lower blood pressure in individuals with untreated elevated blood pressure and whether this will be a greater blood pressure reduction compared with increased consumption of low-nitrate vegetables.

This project is funded by the National Health and Medical Research Council (NHMRC).

African child. Credit: Zoriah

Improving food security in sub-Saharan Africa by developing novel diagnostics for cassava viruses and whiteflies using next generation sequencing (NGS) and high performance computing

Project team: Dr Laura Boykin[1] (leader; email: laura.boykin@uwa.edu.au), Dr Monica Kehoe[2], Dr Peter Sseruwagi[3], Dr Joseph Ndunguru[3]

Collaborating organisations: [1]UWA; [2]DAFWA; [3]Mikocheni Agricultural Research Institute, Tanzania

Cassava brown streak disease (CBSD) presents the most formidable threat to cassava *(Manihot esculenta)* productivity in sub-Saharan Africa. CBSD is caused by two distinct species of single-stranded RNA (ssRNA) viruses, cassava brown streak virus (CBSV) and Ugandan cassava brown streak virus (UCBSV), belonging to the genus *Ipomovirus* of the family Potyviridae. These deadly viruses are transmitted by the whiteflies *Bemisia tabaci.* To stop the spread of these viruses, robust diagnostics must be developed.

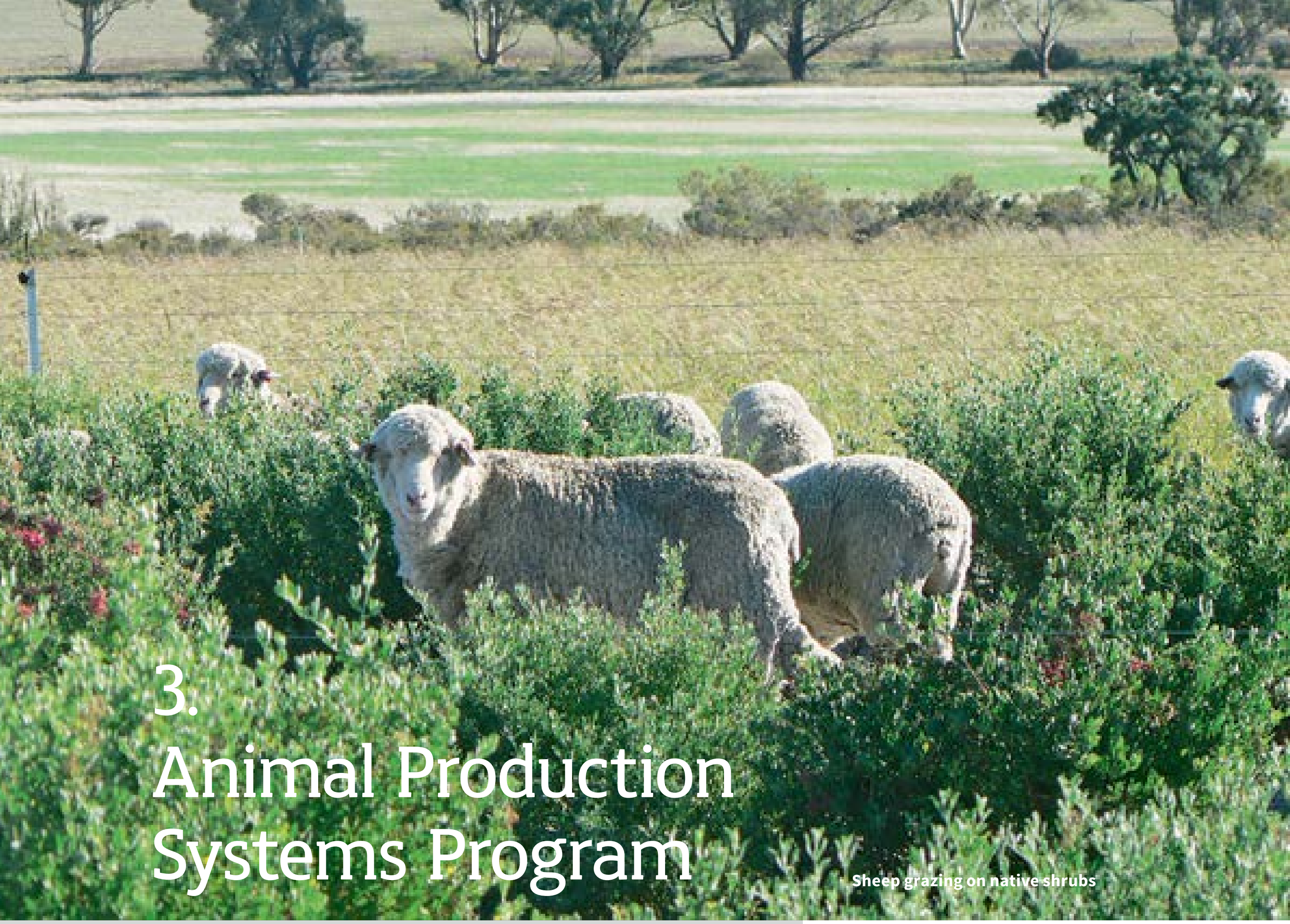
The aims of this research are to undertake whole genome sequencing of cassava mosaic begomoviruses (CMBs) using Illumina sequencing platforms, training in sequencing of RNAs for transcriptomics, and conducting bioinformatics and genomics to analyse sequences for viruses and two local cassava varieties obtained in Africa. Another aim is to develop protocols for NGS of mtCOI and viral sequences in cassava *B. tabaci* and train in sequencing of RNAs, transcriptomics, bioinformatics and genomics.

In December 2014 Dr Peter Sseruwagi and Dr Joseph Ndunguru of the Mikocheni Agricultural Research Institute visited UWA for one month.

Some highlights of the visit included the identification of 12 new CBSV whole genomes from NGS data via bioinformatics training, development of protocols for NGS of individual whiteflies and the production of NGS data for 20 infected plants and six infected whiteflies. Two manuscripts, two grants, one public outreach lecture and two research seminars were given during the visit.

This research is supported by the Bill and Melinda Gates Foundation.

Cassava team Dr Peter Sseruwagi and Dr Joseph Ndunguru with Dr Monica Kehoe and Dr Laura Boykin.



Sheep grazing on native shrubs

3. Animal Production Systems Program

The Animal Production Systems Program is pursuing a vision of 'clean, green and ethical (CGE) systems for livestock management':

Clean – minimise use of hormones, drugs and chemicals;

Green – minimise environmental footprint, especially emissions of greenhouse gas (GHG);

Ethical – maximise animal welfare.

The CGE concept underpins all of our degree programs, outreach activities and research. By its nature, much of the research into CGE management is interdisciplinary and it is also strongly aligned with the 'UWA Future Farm 2050' project. The research within this program has been focused on the role of, and need for, livestock in the landscape, their potential to provide versatility to mixed farming enterprises and minimising their environmental footprint. The strong partnership we have developed with CSIRO's Livestock Industry group at Floreat has enabled us to diversify into versatile livestock systems and livestock management in rangelands.

Methane-fighting forages

The mechanism of antimethanogenic bioactivity of plants in the rumen

Project team: Prof Phil Vercoe[1] (leader; email: 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.

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

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

Project team: Dr Julian Hill[4] (leader; email: 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 (psamment [arenosol] or podsolic sands). 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 the first samples that will be tested in vitro have been collected for measurement of their nutritive value and antimethanogenic potential. These shrubs will be grazed in early 2015 and methane will be measured in-field using a polytunnel system to test whether the animals grazing the pasture that includes shrubs produce less methane.

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

Best choice shrub and inter-row species

Project team: Prof Phil Vercoe[1] (leader; email: 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

Shrubs at Cranbrook research site

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.

In 2014 one such experiment 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. The inclusion of shrubs reduced or, depending on the target rate of liveweight gain, removed the need to supplementary feed the sheep. For every gram of liveweight gain by the sheep grazing shrub–pasture mixtures, hey produced less methane than the business as usual scenario, demonstrating the value of shrub systems for increasing the efficiency of animal production during the autumn feed gap.

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

Nitrate and sulphate rich shrubs to reduce methane and increase productivity

Project team: Dr Hayley Norman[2] (leader; email: 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 project is funded by the Australian Government's Department of Agriculture and AWI.

Host control of methane emissions from sheep

Project team: Prof Phil Vercoe[1] (leader; email: 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. This phase of the project is now completed. Genes with high expression levels in the rumen wall have been identified through the RNA transcriptome analysis and we have

Measuring methane using Portable Accumulation Chambers found unique molecular features with important roles in regulating rumen development, metabolic processes and the local microbiome.

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

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

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

Project team: Prof Phil Vercoe[1] (leader; email: 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 is 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 the *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

Measuring methane at Ridgefield using the polytunnel

have been developed that will be extremely valuable as tools for predicting pasture quality and for informing management decisions.

An animal house experiment is underway to examine the two pasture species with similar nutritional values but contrasting methanogenic potential (i.e. low methanogenic *Biserrula pelecinus* and high methanogenic *Orntithopus sativus*) to confirm that the promising results obtained in the laboratory correspond to what happens in the animal. The findings from this project will assist in developing more productive animal production systems with less methane output.

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

Measuring and managing methane emissions from livestock: from laboratory to landscape

Project team: Prof Deli Chen[2] (leader; email: delichen@unimelb.edu.au), Prof Roger Hegarty[3], Dr Frances Phillips[4], Prof Kourosh Kalantar[5], Dr Tom Flesch[6], Prof Phil Vercoe[1]

Collaborating organisations: [1]UWA; [2]University of Melbourne; [3]University of New England; [4]University of Wollongong; [5]RMIT; [6]University of Alberta, Canada; CSIRO

Methane emissions from the livestock sector account for more than 65% of agricultural emissions or 10.7% of Australia's national greenhouse gas account. Importantly, 94% of the methane emissions from the livestock sector come from microbial fermentation of livestock feeds, with the balance comprising emissions from manure management systems. It is estimated that the beef herd in Australia's northern rangelands is responsible for 6% of Australia's greenhouse gas emissions. This problem must be managed because this industry generates about 45% of the value of northern Australia's estimated total agricultural production (ABARE 2007) through its beef production and extensive grazing systems.

In this project our aim has been to examine the best way to obtain reliable quantification of net methane emissions from the northern beef industry so that we can enhance the development of effective and efficient mitigation and abatement strategies that inform the methodologies of the national inventory.

The first baseline measurements of methane emissions have been obtained from animals grazing in north-west WA. Methane emissions ranged from 113 to 146g CH_4/hd per day, equivalent to approximately 1.3g CH_4 /kg $W^{0.75}$. The *in vitro* gas production system that was used to characterise the methane potential of plants provides a good reflection of the seasonal fluctuations in methane emissions measured on grazing animals using an open path in-field measurement system.

This project is supported by the CSIRO Flagship Collaboration Fund through the University of Melbourne as the lead organisation.

International coordination of the Ruminant Pangenome Project

Project team: Prof Phil Vercoe[1] (leader; email: 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 the 2014 phase of the research program titled Filling the Research Gap Round 2. A highlight has been a successful joint concurrent session at the International Symposium on the Nutrition of the Herbivore/International Symposium on Ruminant Physiology in Canberra in early September 2014. Research in the four commissioned projects in the RPP was presented and this led to a number of important connections to other global initiatives, in particular the EU Methagene project. The two teams plan to work together to establish a more formal network of researchers in this area and facilitate better communication and data sharing.

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

CT scan images of the rumen and its contents for sheep that are either high (left) or low (right) methane producers

Genetics of breeding for breech strike resistance

Project team: Prof Phil Vercoe[1] (leader; email: 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 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.

Wool sourced from the breech area is analysed to identify semiochemicals.

In 2014 a laboratory colony of *Lucilia cuprina* was established, together with a protocol to test the behaviour of flies within the olfactometer using a choice test with wool. The choice test will help determine whether flies make a clear choice between wool samples taken from sheep that have been bred to be susceptible or resistant to flystrike.

In addition, an automated gas chromatography process for analysis of wool samples is being used to produce a data matrix to best detect the odours from the wool that are contributing to flystrike. 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. These unknowns are currently being identified.

This topic is the subject of the thesis work of UWA PhD student Joseph Steer, who was awarded a Mike Carroll Travelling Scholarship to the famous Rothamsted Research laboratories north of London to spend a month with Prof Mike Birkett, a world authority on the physiology of the sense of smell of insects.

This project is funded by AWI.

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

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

Collaborating organisations: [1]UWA; [2]Murdoch University, [3] DPI Victoria, [4]DAFWA

Sheep are fed antimethanogenic pasture legumes to reduce methane emissions

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, that 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 in the CSIRO Animal House 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.

This information was used to plan and establish a two-year plot-scale grazing experiment at UWA Farm Ridgefield at Pingelly. The experiment involves *ad libitum* grazing of the pastures tested previously, plus a 'choice' pasture where the sheep select their own diet from adjacent monocultures of subterranean clover and annual ryegrass. Methane emissions are measured from portable accumulation chambers. Early results show that the growth rates were better for 'choice' (227g/day) and serradella pastures (221g/day) than for subterranean clover (208g/day), biserulla (194g/day) and ryegrass (157g/day). The data from the methane measurements are currently being analysed.

This research is supported by the The Commonwealth of Australia via DAFWA and MLA.

Animal welfare quality assurance (QA) systems for the red meat industry: can Australia learn from the UK and European experience?

Project team: Prof Graeme Martin[1] (leader; email: graeme.martin@uwa.edu.au); Asst/Prof Dominique Blache[1]; Dr Siobhan Mullen[2]; Dr Andy Butterworth[2]

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

Prof Graeme Martin and Assoc/Prof Dominique Blache were asked by MLA to review the on-farm QA systems for animal welfare in the UK and European red meat industries. The specific questions addressed mode of operation, strengths and weaknesses, costs of operation, who manages them, the responses of supermarkets, consumers and the welfare lobby government recognition and support. The information generated was then interpreted in terms of relevance to Australia – what is achievable and practical in our production environment?

Prof Martin was based in the UK during this project so was able to take advantage of the deep expertise and strong industry engagement in the animal welfare centre team at the University of Bristol. In particular, he was helped greatly by Dr Siobhan Mullen and Dr Andy Butterworth.

The UK has two successful QA systems for intensive animal industries, Red Tractor Farm Assurance and Freedom Foods, but they differ in standards and processes and do not include red meat. To overcome these deficiencies, the Assurewel project is developing a harmonised scheme that also improves transparency and traceability, adds measures of welfare outcomes with a systematic progression of standards, and trains animal welfare assessors.

For the Australian red meat industry, Assurewel thus offers a solid foundation upon which we could build, adding context so the scheme would be relevant to our livestock management, transport and processing, supermarkets and consumers. The scheme could be paid for by government, by individual supply chain participants, or through an independent structure that is funded by contributions from all stakeholders. The outcome would be an animal welfare QA scheme that would ensure a long-term future for our domestic and export markets for Australian red meat.

This research is supported by MLA.

Murdoch–UWA collaboration on enhancing lamb survival

Project team: Dr Andrew Thompson[1] (leader; email: andrew.thompson@murdoch.edu.au); Dr Andrew Currie[1]; Dr Shimin Liu[2]; Dr Serina Hancock[1]

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

Lamb mortality reaches about 30% in the Australian sheep industry. This MLA project aims to investigate the effects of supplementation of vitamin E plus selenium (Se), vitamin D or rumen protected methionine during the last six weeks of pregnancy in 240 merino ewes, on lamb survivals until weaning, immune responses and the status of these nutrients in the body in Mediterranean climate conditions.

The field experiment was carried out at UWA Farm Ridgefield. Without the supplements, the ewes had insufficient vitamin E, but sufficient vitamin D during late pregnancy and early lactation; Se supply from feeds was below the requirement. The young lambs had very low vitamin D status, even with vitamin D supplements, due to a poor supply of this vitamin from colostrum and milk. The lamb survival rate by weaning increased about 10% by each of three supplements, which needs a statistical confirmation using a sufficient number of ewes. The shift of the antioxidant status, assessed as the ratio of reduced to oxidised glutathione in whole blood, during the pariparturient period was evident. The immune responses, such as plasma IgG, specific antibody titre to the stimulant, lymphocyte profiles, and pathogen profiles, to the nutrient supplementations remain under investigation.

This research is supported by MLA.

Gene polymorphisms associated with temperament in merino sheep

Project team: Ms Xioayan Qiu[1] (leader; email: 21101419@student.uwa.edu.au); Assoc/Prof Dominique Blache[1], Prof Graeme Martin[1], Dr Shimin Liu[1]

In sheep, a calm or nervous temperament can have major effects on productivity and welfare. Importantly, it can be changed by genetic selection. The UWA temperament flock comprises two lines of merino sheep that have been bi-directionally selected for 20 generations for extreme behavioural reactions to two stressors: social isolation and human presence.

Ms Xiaoyan Qui

This makes them ideal for studying the physiological and behavioural responses of animals to stressful situations. A major physiological pathway involves the secretion of cortisol by the adrenal gland, so we need to understand how temperament affects the brain–pituitary–adrenal system. The behavioural responses, seen in humans as mood characteristics and emotional reactivity, are mostly implemented through the brain centres that control motor activity via the neurotransmitter, dopamine.

Until this project little was known about the effects of genetic selection for temperament on these two systems. We have found evidence that both are affected, through two specific genes that differ between nervous and calm sheep: (i) in regard to behaviour there are polymorphisms in genes for the Dopamine Receptor 2 (DRD2), and in the gene for the enzyme (monoamine oxidase) that breaks down dopamine in brain tissue; and (ii) in regard to the adrenal axis there is a polymorphism in CYP17, the gene responsible for cortisol production.

During 2014 the project advanced significantly, as reflected by three major accomplishments: (i) we identified two single-gene nucleotide polymorphisms (SNPs) associated with temperament, one in the CYP17 and one in the DRD2 gene; (ii) we validated both SNPs as genetic markers for temperament selection; and (iii) we described the association between both SNPs and cognitive learning abilities in sheep.

We are thus heading towards the possibility of genomic markers that we can use to select for temperament, and thus improve the welfare of sheep in production systems.

This research is supported by UWA.

Determining the importance of a nest to laying Pekin ducks

Project team: Ms Lorelle Barrett[1] (leader; email: lorelle.barrett@research.uwa.edu.au); Asst/Prof Dominique Blache[1], Prof Shane Maloney[1], Adj/Prof Irek Malecki[1]

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 the habit 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 not clear whether floor-laying ducks suffer poorer welfare than nest-laying ducks.

This project uses behavioural demand, 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 affecting nest use by Pekin ducks and develop recommendations to improve both production and welfare outcomes for the industry.

The experimental work for this project commenced in September 2014. We have developed a behavioural demand method for ducks and a strategy to habituate ducks to use the device. We are now using this testing apparatus in an on-going experiment to establish how motivated female ducks are to access a preferred nest site. Sample collection for physiological indicators of welfare also commenced.

This research is supported by Poultry CRC and RSPCA Australia.

Ducks in the testing range

Fleece characteristics and health of alpacas in southern Australia

Project team: Ms Kelsie Moore[1] (leader; email: 20146747@student.uwa.edu.au); Assoc/Prof Dominique Blache[1], Prof Shane Maloney[1]

Collaborating organisations: [1]UWA; Banksia Park Alpaca Stud

Alpacas were bought to Australia from the Andes in South America to establish a niche fibre industry. They evolved in a high-altitude, alpine environment that is much cooler than Australia yet has far more intense ultraviolet radiation. It was not known whether the ability of the fleece to insulate the animals, and thus maintain temperature homeostasis in the cold, would also be effective for adaptation to a high intensity of radiant heat, and thus avoid heat stress during an Australian summer.

Additionally, as a young industry in Australia, the objectives to breed towards higher quality and quantity of fleece characteristics for an optimal product, has resulted in variable fleece types (from combinations of fleece characteristics) attained across the national herd.

The objectives of this research were to investigate how these combinations of fleece characteristics in southern Australia affect: (i) the ability of the fleeces to insulate against radiant heat; (ii) the potential of alpacas to sweat to remove additional heat; (iii) the potential of the fleece to block out ultraviolet radiation and thus inhibit the synthesis of vitamin D.

We have found that selection of alpacas for specific combinations of fibre characteristics has no effect on their thermoregulatory health or vitamin D status, but it is the management of the animals in regards to time of year for shearing and dietary supplementation that have the greatest implications on the alpacas health.

This research is supported by UWA.

Nutrition affects sperm production and sperm quality by inducing molecular and morphological changes in the testes

Project team: Ms Yongjuan Guan[1] (leader; email: 21004548@student.uwa.edu.au), Prof Graeme Martin[1], Adj/Prof Irek Malecki[1], Dr Penny Hawken[1]

In our agricultural regions the normal breeding season for sheep falls in autumn, at the end of the hot, dry summer, when pasture is at its worst. Therefore, under-nutrition, with concomitant losses of body mass and testis mass, is typical for our rams. We know that the loss of testis mass leads to a fall in sperm production, but this is generally not considered important because it does not become evident until the end of the mating period. However, we persistently have low fertility in our merino flocks, so other explanations are needed.

Health of alpacas dependant on good management

This project aims to investigate the basic molecular and cellular biology of the ram testis, with a focus on the effects of under-nutrition on the sperm and on the Sertoli cells (the cells that 'nurse' the developing sperm). We tested whether nutrition affected the number or the function of the Sertoli cells.

With under-nutrition, the ram sperm move less efficiently, undergo more apoptosis (cell 'suicide') and carry more damaged DNA. These problems seem to be caused by the effects of under-nutrition on the Sertoli cells. There is no change in the number of the Sertoli cells, but they do seem to regress (becoming less like Sertoli cells) and the tight junctions between adjacent cells are disrupted. These junctions are essential for protecting the developing sperm.

To understand the mechanisms involved, we also studied 'small RNAs'. Small RNAs are transcribed from DNA but, rather than producing a protein, they regulate the transcription of other genes. In collaboration with Prof Le Luo Guan (University of Alberta, Canada), we found 77 small RNAs that are expressed differently in testicular tissue from well-fed and under-fed animals. In addition, we found one novel 'micro-RNA' that seemed to have a major role in germ cell apoptosis. The results were excellent and of major significance in reproductive biology.

We now have a clearer understanding of the molecular and cellular biology of the ram testis and how it responds to under-nutrition. This re-enforces the need to feed rams well before mating because the quality of their sperm will decline otherwise. In the long term, we should be able to use this new information to inform genomic selection programs to develop rams that are resistant to the effects of under-nutrition on their fertility.

This research is supported by UWA.

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

Project team: Ms Stacey Rietema[1] (leader; email: stacey.rietema@uwa.edu.au); Assoc/Prof Dominique Blache[1], Prof Graeme Martin[1], Dr Penny Hawken[1]

Breeding for temperament is seen as a tool for improving the welfare, ease of handling, and productivity of livestock. In sheep, cattle, and poultry, a calm temperament is linked to smaller responses to stressors, particularly cortisol, an important hormone for controlling major processes in the body, including growth, reproduction and immune function.

We have been testing whether selection for temperament in sheep affects the normal pattern of cortisol secretion or the magnitude of the cortisol response to stressors. We studied the normal pattern by measuring the blood concentrations of cortisol every 20 minutes for 24h, in calm and nervous sheep. To test whether temperament affects the responsiveness of the system that controls cortisol responses to stressors, we measured the speed and magnitude of the response of the pituitary gland and the adrenal gland to a hormonal stimulus. The pituitary gland was stimulated with arginine vasopressin and corticotrophin releasing hormone, or a mixture of both. The adrenal gland was stimulated with a range of doses of adrenocorticotrophic hormone. Temperament did not affect the daily pattern of cortisol concentrations, or the speed or magnitude of cortisol response in any of our experiments. We therefore conclude that the effects of temperament on the cortisol response to stressors are not due to differences in the pituitary-adrenal axis, so must be due to differences in the initial brain perception of the stressor.

This research is supported by UWA.

4. Rural Economy, Policy and Development Program

The Rural Economy, Policy and Development Program aims to enhance the sustainability of rural industries, communities and regions. This is achieved through innovative education and research with a focus on: improving rural productivity and prosperity; addressing their environmental challenges; contributing to their broader economic and social development; and enhancing rural policy and planning processes.

Here we highlight some of the ongoing research projects in this program.

Foreign investment in mixed crop–livestock farms

Project team: Asst/Prof Marit Kragt[1] (leader; email: marit.kragt@uwa.edu.au), Prof Fiona Gibson[1], Mr Fraser Stewart[1]

Foreign investment in Australian farms has generated significant debate in farming communities and among the general public. Foreign investment presents opportunities and potential benefits to Australian farmers with various scales of operation. For example, small-scale family farms may benefit from joint ventures with foreign investors, and foreign ownership may offer increased opportunities for expansion through farm leasing.

The type of business structure that a foreign investor employs – joint venture, ownership, leasing – is likely to pose varying benefits, risks and challenges to farmers.

This project used semi-structured interviews with agriculture experts, and with farmers in the WA wheatbelt who are, directly or indirectly, involved with foreign investment companies. The results were as follows.

The main collaborative business structures are ‘fully owned and operated’ by foreign investors, and land owned by foreign investors but leased to Australian farmers (‘own and lease’).

Farmers in the WA wheatbelt generally have positive opinions about foreign investors, who are perceived to provide job opportunities for local people. Foreign owned farms are perceived to make an effort to purchase inputs locally, and corporate farms contribute to the local community by supporting emergency services and sporting clubs, sponsoring events and participating in field trials.

Foreign investors are perceived to manage their natural resources as well, if not better, than local family farms because investors have more funds available for environmental management and because corporate farms are more accountable for the way they manage their natural resources. Foreign investment was said to bring money into the rural communities and create a market for sellers of large farms.

Some risks associated with foreign investment were also identified.

Fraser Stewart in the family Toodyay farm.

For example, own-lease farms were perceived to charge higher prices for leasing land, and own-operate farms may not benefit local farmers if employees are sourced from outside the region. In our study area, however, farm managers on foreign owned farms were usually Australian families.

Foreign investment may be beneficial to farmers looking to sell, but they create additional competition to farmers who are seeking to purchase additional land. There is a risk that foreign investors are able to offer a higher price for land, which reduces the opportunities for local farmers to expand through land purchases.

This project is supported by the Mingenew Irwin Cropping Group and the Sir Eric Smart Bequest through the IOA.

Novel business structures for adaptation to a changing climate

Project team: Prof Ross Kingwell[1,2] (leader; email: ross.kingwell@agric.wa.gov.au), Dr Jason Crean[3], Adj/Prof Bill Malcolm[4]

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

This project examines how novel business structures might allow farm businesses to better adapt to a changing climate and be transformed. We hypothesise that some non-traditional farm business structures can out-perform traditional farm business structures. Advantages and disadvantages of traditional versus novel farm business structures are contrasted, drawing on actual case studies and constructed hypothetical case studies.

This research is supported by DAFWA's 'Filling the Research Gap: Round Two'.

Benchmarking the performance of farm enterprises

Project team: Asst/Prof Amin Mugera[1] (leader; email: amin.mugera@uwa.edu.au), Assoc/Prof Atakelty Hailu[1], Prof Michael Burton[1], Ms Rebecca Owusu[1], Mr Steele West[1], Dr Luke Abatania[1], Mr Robert Khataza[1], Mr Govinda Sharma[1], Mr Zhihai Yang[1]

A common objective of many agricultural development projects is to promote output growth (productivity) by inducing upward shifts in the production frontier (technical progress) while promoting better management (efficiency improvement). Equally important is understating the linkage between productivity and profitability growth. A good understating of levels of both productivity and profitability and factors that influence them is important for designing policies that promote the growth of the agricultural sectors, in both developed and developing countries.

A series of projects were conducted to measure and understand factors that drive farm level productivity and profitability in different countries. Asst/Prof Amin Mugera investigated the impact of debt structure on the production efficiency of broadacre farms in WA. PhD candidate Steele West analysed farm level panel data for WA to investigate determinants of technical efficiency and production risk. Visiting PhD scholar from Huazhong Agricultural University, Zhihai Yang, investigated environmental efficiency for rice farms on the Jianghan Plain, China. Dr. Luke Abatania completed a dissertation titled 'Identifying performance benchmarks for Ghanaian farm households through efficiency analysis'. PhD candidate Rebecca Owusu conducted a survey in Ghana to investigate economic efficiency in rice production. PhD candidate Robert Khataza conducted a survey in Malawi to investigate whether adoption of integrated maize–legume soil fertility management practices offer significant incentives and benefits to farmers. PhD candidate Govinda Sharma continued to investigate productive efficiency of coffee production in Nepal. Dr Abatania Luke, Mr Arif Watto, Mr Manoj Mudalinge, Ms Rebbeca Owusu and Asst/ Prof Amin Mugera presented preliminary results of their studies at the 12th International Conference on Data Envelopment Analysis in Kuala Lumpur, Malaysia, in April 2014.

This research is supported by AUSAID, the China Scholarship Council and UWA.

Picture taken at University of Malaya, Malaysia. From left: Manoj Mudalinge, Luke Abatania, Rebecca Owusu, Dr. Banker, Dr. Amin Mugera and Arif Watto.

Consumer preferences in food marketing

Project team: Asst/Prof Amin Mugera[1] (leader; email: amin.mugera@uwa.edu.au), Prof Michael Burton[1], Asst/Prof James Fogarty[1], Ms Emma Downsborough[1], Ms Jacinta Paterson[1]

Consumers increasingly are concerned about how their food is produced, as well as the characteristics of the product on their plate. They care about the prices they pay for products, the product quality, and other production and marketing aspects, such as animal welfare and environmental characteristics of production, and food labelling and advertising. However, consumers would not necessarily trust producers who claim to be providing certain benefits. Some form of reliable labelling system is needed for consumer preferences to be translated into market demand.

Asst/Prof James Fogarty investigated the impact of providing energy content information at the point of sale in Australian fast-food chain restaurants. A key research finding was that providing information on the energy content of menu items at the point of sale results in consumers selecting menu items that, on average, have lower energy content. In males the effect is statistically significant, but in females the effect is not. Provision of energy content information was found to have little impact on the average consumer per transaction spending.

Asst/Prof Amin Mugera, Prof Michael Burton and Ms Emma Downsborough investigated consumer preference and willingness to pay for a local label attribute in Western Australian fresh and processed food products. A choice experiment using one fresh and one processed food product (skinless chicken breast and fruit yoghurt) was conducted to assess willingness to pay for a local production attribute and other label claims. Consumer awareness and preference for local foods was found to be high. However, this high preference is not because the product is locally produced but because of the local attributes associated with high quality products. The study highlights the importance of successfully differentiating products through credible labelling schemes in order to capture market premium.

Honours student Ms Jacinta Patterson investigated whether consumers care about poultry welfare and are willing to pay a premium for poultry products with the RSPCA logo in WA. Data from an internet-based choice experiment on skinless chicken breast was analysed to determine whether consumers care about humane production practices. The majority of respondents are concerned about the welfare of meat chickens. In general, consumers are most concerned about stocking density, hot metal blade beak trimming and poor litter quality. Consumers are willing to pay substantial premiums for welfare friendly broiler products.

This research is supported by DAFWA and UWA.

Financial models for agricultural risk management in Western Australia

Project team: Mr Zhibo Guo[1] (leader; email: zhibo.guo@research.uwa.edu.au), Asst/Prof Amin Mugera[1], Prof Ben White[1]

Agriculture is inherently a risky business and the grain industry in WA is exposed to both price volatility and yield variability. Different yield prediction models have been developed to help farmers predict yield risk. Farmers also have the option of managing price risk by using futures markets contracts. What farmers need are tools that can help them manage their crop revenue risk by managing the interaction of both price and production risk.

The aim of this project is to evaluate revenue risk for wheat enterprises in WA. This is achieved by investigating empirical yield distributions and incorporating historical weather data in crop simulation models to predict yields. This information together with futures price data are used to determine the optimal amount of contracts that a typical farmer in WA should hold.

This research is part of a PhD candidature supported by a UWA SIRF scholarship and University Postgraduate Award for International Students (UPAIS).

Vulnerability of households' consumption to idiosyncratic and covariate shocks: equity efficiency trade-off in mitigation investments

Project team: Mr Muhammad Masood Azeem[1] (leader; email: masood.azeem@research.uwa.edu.au), Asst/Prof Amin Mugera[1], Assoc/Prof Steven Schilizzi[1], Hackett Prof Kadambot Siddique[1]

Households in Pakistan are frequently hit by various idiosyncratic and covariate shocks. The magnitude and frequency of such shocks result in high consumption vulnerability. Given limited resources and time, the fundamental question is how to prioritise 'vulnerability' reduction investments. More specifically, according to which criterion/criteria should the scarce resources be allocated to safeguard household/community X as compared with household/community Y?

However, in order to answer the above question, we first need to know what is being minimised. More specifically how do we understand the concept of 'vulnerability'? What is the level of vulnerability across different households? What is the distribution of vulnerability across different regions of Pakistan? What are the causes of vulnerability? Is household vulnerability structural or risk induced? If it is structural, what are the characteristics of the households which make them vulnerable? If it is risk induced, what is the contribution of idiosyncratic and covariate shocks in causing this vulnerability?

In 2014 household vulnerability was examined using monetary and non-monetary indicators of poverty. A large cross-sectional data of about 90,000 households distributed across 150 Tehsils of the Punjab province of Pakistan was used. The results of this research suggest that vulnerability estimates are not comparable across various regions of the Punjab using both metrics. Hence, monetary metric (i.e. $2 a day) cannot serve as an alternative for non-monetary metric measure (i.e. food insecurity) of vulnerability to poverty. Given this conclusion, a separate estimate of the impact of idiosyncratic and covariate shocks on household vulnerability to monetary poverty and food insecurity is being calculated.

This research is part of a PhD candidature and is supported by UWA.

The economics of groundwater for irrigation in Pakistan

Project team: Mr Arif Watto[1] (leader; email: arif.watto@research.uwa.edu.au), Asst/Prof Amin Mugera[1], Prof Ross Kingwell[1]

Water shortage is a major challenge for agriculture in Pakistan. With decreasing surface water availability, most farmers now depend on groundwater resources for irrigation. The rate of annual groundwater extraction is estimated to be much higher than the recharge rate. The consequence of unregulated extraction and use of groundwater is the lowering of the watertable and salinity problems in most parts of the country.

The aim of this research project was to analyse the economics of groundwater use in irrigated agriculture in the Punjab province of Pakistan. The objectives were to: (i) investigate the impact of groundwater markets on farm productivity; (ii) analyse groundwater use efficiency across different cropping enterprises; and (iii) investigate the impact of groundwater pricing on water demand and crop enterprise allocation.

This research is part of a PhD candidature and is supported by UWA and a UAF Pakistan SIRF scholarship.

Tube-well in Punjab, Pakistan

The economics of rice production and consumption in Sri Lanka

Project team: Mr Manoj Mudalinge[1] (leader; email: manoj.mudalinge@research.uwa.edu.au), Asst/Prof Amin Mugera[1], Prof Ben White[1]

Food and nutrition security is a major concern for many developing countries, including Sri Lanka. Although Sri Lanka is currently self-sufficient in rice production, it is projected that demand will outstrip supply by 2030 due to population growth and rice yield stagnation. However, increasing rice production will have to be done under limiting land, water and labour resources. As average household income increases, it is also projected that food consumption will gradually shift from traditional diets towards more processed high valued diets. Although subsequent governments in Sri Lanka have provided welfare grants to vulnerable groups in the form of food subsidies to boost food security, it remains uncertain whether food subsidy programs actually improve nutritional security.

The purpose of this project was to investigate socio-economic factors that contribute to low rice yields and how consumers substitute rice for other foods as food prices and incomes change.

The objectives were to: (i) evaluate the productive efficiency of irrigated versus rain-fed production systems in bridging the rice yield gap; (ii) analyse whether there is any abuse of subsidised fertiliser by estimating fertiliser use efficiency; (iii) investigate how use of different inputs and other socio-economic factors drive rice yield variability; and (iv) investigate how the demand for rice is affected by changes in the price of other foods and the income of consumers.

This research is part of a PhD candidature and is supported by UWA and an Endeavour Award.

Sri Lankan woman in the rice paddy. Credit: Aitor Garcia Vinas

The dynamics of poverty in developing countries

Project team: Asst/Prof Amin Mugera[1] (leader; email: amin.mugera@uwa.edu.au), Ms Monika Bajimaya Shrestha[1], Ms Diana Metaute Heredia[1], Ms Eunice Alloo[1], Asst/Prof Ram Pandit[1]

Eradicating poverty is the number one objective for the Millennium Development Goals. Most governments in developing countries and international development agencies are also concerned about poverty and how to alleviate it. However, poverty is both dynamic and multidimensional. People fall into and get out of poverty over time; poverty is also multifaceted and encompasses deprivations in many dimensions besides income.

Designing effective poverty intervention strategies requires knowledge and information not only about the current status of poverty but also the likelihood of individuals getting in and out of poverty in the near future and the dimensions where they are mostly deprived.

The purpose of this project is to investigate poverty using the multidimensional approach and estimate vulnerability to poverty across different developing countries. Analysis is accomplished using the data from the Living Standards Surveys implemented by the World Bank in conjunction with different governments in development countries.

MSc candidate Diana Metaute Heredia used repeated Living Standards Measurement Surveys (LSMS) conducted by the National Statistical Department from 2010 to 2013 to analyse multidimensional poverty in Columbia. Five dimensions of poverty were considered: education, employment, children and youth, health and housing. Deprivation in employment and education are found to be the major drivers of overall multidimensional poverty. Deprivation in children and youth conditions is also alarming, whereas deprivation in health access and services is the least experienced by the population. MSc candidate Monika Shrestha used the Living Standards Survey 2011 to analyse vulnerability to poverty in Nepal. The results reveal that total vulnerability to poverty is higher than the observed poverty rate. The results also demonstrate that there are significant regional poverty disparities with people in remote areas and marginalised groups more vulnerable to poverty. MSc candidate Eunice Alloo used the Living Standards Survey 2013 survey to analyse vulnerability to poverty in Uganda.

This research was supported by UWA.

Improving productivity, postharvest handling, safety and biosecurity of cowpeas and Bambara groundnuts: a value chain analysis in eastern and southern Africa.

Project team: Dr Casper Madakadze[2] (leader; email: casper.madakadze@up.ac.za), Asst/Prof Amin Mugera[1], Prof Shashi Sharma[3], Prof Victor Olusegun Okoruwa[4], Prof Kwaky Gyebi Duodu[2], Prof John Muyonga[5], Prof P Johnston[6]

Collaborating organisations: [1]UWA; [2]University of Pretoria, South Africa; [3]Murdoch University; [4]University of Ibadan, Nigeria; [5]Makerere University, Uganda; [6]Cape Town University, South Africa

Cowpeas and Bambara groundnuts are legume crops grown for their protein rich seeds and (in the case of cowpeas) their leaves, and are a relatively inexpensive source of protein in the diets of people throughout sub-Saharan Africa. The legumes are drought resistant and have great potential in smallholder farmers' adaptation to climate change and variability. However, overall productivity of the legumes in the existing traditional legume–cereal intercropping system is very low. The market for the legumes is also underdeveloped. Therefore there is need to increase the productivity of the crops through improved crop varieties, and improve both postharvest handling and processing, including marketing and biosecurity.

The aim of this project is to investigate the binding constraints in the productivity and postharvest handling of cowpeas and Bambara groundnuts in eastern, western and southern Africa.

The project was given seed money by the Australia Africa University Network (AAUN) to organise a collaborative and targeted research group of AAUN member universities and other education and research partners to develop a full research proposal for the project.

The project was successful in building a multidisciplinary team and conducting a workshop at the University of Pretoria, South Africa, in April 2014. At the workshop a framework to guide the development of the multidisciplinary research proposal was crafted. Beyond the workshop, the team hopes to continue working together virtually to develop a full proposal that can attract funding.

This research is supported by AAUN.

Development of conservation cropping systems in the drylands of northern Iraq: socio-economic analysis

Project team: Asst/Prof Amin Mugera[1] (leader; email: amin.mugera@uwa.edu.au), Hackett Prof Kadambot Siddique[1], Dr Yigezu Yigezu[2], Dr Saad Mohammed[3]

Collaborating organisations: [1]UWA; [2]ICARDA; [3]Ministry of Agriculture, Iraq

The overall purpose of this project is to increase crop productivity, profitability and sustainability in dryland areas of northern Iraq by promoting the adoption of conservation cropping practices to farmers. The project has key objectives related to extension, research and development, seed production, socio-economic analysis and training.

The main objective of socio-economic analysis was to evaluate the adoption and impact of conservation cropping, identify constraints and enable policy options for uptake by farmers. In this context, farm-level analysis was conducted to evaluate the effects of adoption of ZT technology on the welfare of farmers and on production and resource use efficiency.

A book chapter and two manuscripts were written. Three selected papers were also presented at the 6th World Congress of Conservation Agriculture in Winnipeg, Manitoba, in June 2014.

Two principal researchers, Dr Yigezu Yigezu from the ICARDA office in Jordan and Dr Saad Mohammed from the Ministry of Agriculture in Iraq, visited UWA in September 2014 for the purpose of consultations and preliminary analysis of survey data collected in Iraq.

This research is supported by ACIAR.

Dr. Saad Mohammed, Ass Prof Amin Mugera and Dr. Yigezu Yigezu in September 2014. The team analysed survey data from Iraq.

5. Education, Outreach and Technology Exchange Program

The Education, Outreach and Technology Exchange Program is a key area for the Institute. Through this program we aim to raise UWA's profile in agriculture and related areas by translating the research achievements made across the other four programs into tools our end users can use.

The program fosters industry relations, strengthens links with rural communities, promotes research partnerships, postgraduate teaching, and agribusiness activities at UWA, regionally, nationally and internationally.

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.

IOA Postgraduate Showcase

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, nine 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 2014, the eighth consecutive event.

The Honorable Ken Baston, MLC, Minister of Agriculture and Food, Fisheries WA gave the opening address, and the two sessions were chaired by Dr Terry Enright, Chair of the IOA Industry Advisory Board, and Prof Philip Dolan, Dean of The UWA Business School.

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

Ms Delma Poniman	What are the issues regarding adoption of traceability systems in the Halal supply chain?
Ms Anjani Weerasekara	Removing excess phosphorus during the piggery waste treatment process to create a more stable phosphorus fertilizer
Mr Bidhyut Banik	Biserrula pelecinus L., a pasture legume that can help reduce methane emission ('burps') from sheep and cattle
Ms Yiming Guo	Screening for drought tolerance in Brassica
Ms Isabel Arevalo-Vigne	Alliance against the common foe: community management of Mediterranean fruit fly
Mr Arif Watto	Does the risk of groundwater depletion drive technology adoption and irrigation water use efficiency? Lessons from the Indus Basin, Pakistan
Mr Mike Ashworth	Agricultural weed control on wild radish without producing herbicide resistance – can it be done?
Ms Louise Fisk	Do soil carbon additions decrease the risk of nitrogen loss from semi-arid cropping soils?
Lynne Johnston	Who governs: the determinants of Board membership in primary producer representative organisations

Website

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 2014, an online registration form for events was set up through the website. The form captures personal details about event attendees, including how they heard about the event. An automatic email confirmation is sent to the registrant, minimising administration time and providing vital information about which publicity avenues are most effective. Participant details are captured and added to IOA's mailing list.

In addition, an online post-event evaluation was developed and circulated to all event participants, providing IOA with critical information about what worked well and what could be improved on next time.

Another positive development for 2014 was the implementation of an online booking system to reduce administration managing visitors and researchers to UWA Farm Ridgefield. The booking system is available for staff and students and is password protected. Health and Safety requirements are distributed through the booking system.

Public Lectures

In 2014, IOA hosted five public lectures (see www.ioa.uwa.edu.au/publications/lectures)

Date	Presenter	Organisation	Title
28 January 2014	Prof Christine Foyer	Centre for Plant Sciences, University of Leeds, UK	Glutathione: From the chloroplast to the nucleus and back
15 September 2014	Prof Mark Eisler	Chair in Global Farm Animal Health, University of Bristol, UK	Steps to sustainable livestock and the Global Farm Platform
22 October 2014	Mr Simon Johnson	General Manager, Australian Export Grains Innovation Centre	Increasing the competitiveness of Australia's export grain
8 December 2014	Dr Joseph Ndunguru	Head, Mikocheni Agricultural Research Institute, Dar-Es-Salaam, Tanzania	Two novel DNAs associated with cassava begomoviruses enhance disease symptoms, break resistance and are found integrated in most cassava genomes
8 December 2014	Dr Peter Sseruwagi	Mikocheni Agricultural Research Institute, Dar-Es-Salaam, Tanzania	Understanding *Bemisia tabaci*: the driver of viral disease epidemics in cassava in sub-Saharan Africa

Media Statements

IOA continued communicating its research outcomes to the general public through the media by distributing 37 media statements in agriculture and related areas throughout 2014.

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

Date	Title
15 January 2014	Move over elephants – plants have memories too
20 January 2014	Project to assess whether we're going against the grain in training
21 February 2014	Imaging technology used to class grains and food
27 February 2014	What's critical about the earth's outer skin?
4 March 2014	Fulbright Scholarships awarded to three from UWA
6 March 2014	National innovation award for ground-breaking water stress sensor
28 March 2014	Drying climate leads to push for water law reform
29 April 2014	Green vaccination: boosting plant immunity without side effects
2 May 2014	Horizon Scholarship to groom two new UWA students for a future in agriculture
7 May 2014	Water-saving innovations in Chinese agriculture
20 May 2014	Plant researchers sow seeds of major disease breakthrough
29 May 2014	UWA links to finalists in West Australian of the Year Awards
30 May 2014	Solving the puzzle of a clever fungus
2 June 2014	UWA people honoured at Western Australian of the Year Awards
11 June 2014	Blast from the past gives wheat a boost
17 June 2014	Co-operative decade ahead for new UWA research unit
18 June 2014	Wheatbelt bee and wasp networks may signal global change
19 June 2014	Measuring efficiency on Pakistan's cotton farms
2 July 2014	National recognition for UWA research student
22 July 2014	Strong showing of UWA finalists in Premier's Science Awards
4 August 2014	Lentils provide breakthrough in disease prevention
7 August 2014	Record numbers at The UWA Institute of Agriculture's Industry Forum
12 August 2014	Australian agriculture builds on world expertise
14 August 2014	World's largest drought resistance experiment on chickpeas under way at UWA
15 August 2014	UWA climbs higher in world rankings
21 August 2014	Canola flowers faster with heat genes
18 September 2014	New research provides understanding that helps control legume viruses
29 September 2014	UWA commits to sustainable farming
8 October 2014	Enhanced tolerance to ion toxicities improves wheat yield in WA
20 October 2014	UWA showcases research strengths in Shanghai
29 October 2014	Medicine and agriculture to benefit from work of UWA's Australian Life Scientist of the Year
4 November 2014	Chinese wonder fruit genome to aid world fruit breeding
5 November 2014	Smart legacy in agriculture continues
6 November 2014	UWA teams with Yara for free agricultural course
13 November 2014	Strategies to reduce greenhouse gas emissions must be financially attractive
20 November 2014	Breakthrough in understanding wheat virus epidemics improves control options
18 December 2014	TED Fellowship for Australian computational biologist

Outreach and teaching activities at UWA Farm Ridgefield

Minister for Agriculture, Food and Fisheries WA, the Hon Ken Baston visited UWA Farm Ridgefield in May 2014. The purpose of the visit was to update the Minister on the research being conducted on the farm. The Minister acknowledged UWA's investment in the farm and said he was impressed by UWA's long term approach to R&D, and for conducting trials on a scale relevant to commercial farming operations.

In April 2014, UWA hosted an international workshop to mark the establishment of Australia and the southern hemisphere's first Critical Zone Observatory (CZO), which was established at UWA Farm Ridgefield in 2013. The workshop brought together local researchers and international experts in CZO's for two days of presentations, workshops and planning future research. Participants visited UWA Farm Ridgefield to hear about the unique landscape, geology and soils at the site.

UWA Farm Ridgefield joined two other networks in 2014. The UN's Food and Agriculture Organisation (FAO) accepted the Farm into its directory of best practice models in grassland, rangeland and pastoral management. This enables the team to contribute to technical and policy guidelines for sustainable grassland management in a range of environments worldwide.

The Farm also joined the global Nutrient Network or *NutNet*, a global research network that aims to assess the ecological factors driving plant community dynamics in a variety of different systems.

UWA hosted delegates representing ten universities and three research agencies at the Worldwide Universities Network (WUN) Global Farm Platform in September 2014. The delegation were given a tour of the Farm including demonstrations of methodologies of greenhouse gas emissions from sheep and impacted experimental paddocks planted with anti-methanogenic shrubs.

In March 2014, more than eighty students and staff from the Crawley and Albany campus visited the Farm over a weekend to study the soils.

UWA undergraduate students enrolled in a soil science unit, Land Use Management (EART3338) conducted soil sampling and assessment of the physical and chemical properties of the soil at the Farm.

Student volunteers contributed to planting 2,500 native trees and shrubs during an overnight visit to the Farm in July 2014. The trees were planted to enhance the biodiversity value of surrounding remnant vegetation, the final phase of a project to ensure water

Student group excavating a soil pit at UWA Farm Ridgefield

UWA-CAAS MoU is signed

security for farm operations. The tree planting exercise was supported by UWA Facilities Management as part of their carbon offset commitment.

Students from three city high schools, Applecross Senior High School, John Curtin College of the Arts and Ardross Primary School also planted trees on the farm as part of the 'City Kids to the Country' Program. 2014 is the first year the program has been incorporated into a research project at the Farm, so that monitoring and evaluation will be ongoing.

For further details about the UWA Farm Ridgefield's outreach activities, visit ioa.uwa.edu.au/future-farm-2050/news-and-events

Collaborations with overseas institutions

Flourishing alliances with China

UWA-CAAS collaboration

In February 2014, a Memorandum of Understanding (MoU) designed to strengthen existing links and develop new collaboration between the prestigious Chinese Academy of Agricultural Sciences (CAAS) and UWA.

UWA's existing collaborations extend across six CAAS Institutes: The Oilseed Crop Research Institute, the Institute of Vegetables and Flowers, the Institute of Plant Protection, the Institute of Crop Sciences, the Institute of Agricultural Resources and Regional Planning, and the Institute of Animal Science and Veterinary Medicine.

The discussions identified two further CAAS research institutes that have collaborative potential at UWA. The two institutions decided to hold a joint workshop on integrated dry-land agricultural production systems in 2015.

Joint Centre for Plant Functional Genomics and Crop Genetic Improvement

Huazhong Agricultural University, China is one of the top agricultural universities in the country. A Joint Centre for Plant Functional Genomics and Crop Genetic Improvement was established in April 2014. The Joint Centre agreement defined eight key areas to promote research and training collaboration, including crop nutrient and energy efficiency, disease and pest resistance and stress tolerance.

Agriculture teaching between UWA and Chinese Universities

Students and academics from Northwest Agriculture and Forestry University, and South China Agricultural University spent the month of July at UWA for an intensive training and cultural program organised by *UWA Extension*. The students learnt about the agricultural systems in WA and visited UWA Farm Ridgefield to learn how to integrate farming practices with dryland ecosystem management.

Capacity building in Iraq

In April 2014, a UWA delegation visited the Kurdish Regional Governorate (KRG) in Erbil, northern Iraq. The aim of the visit was to meet with officials from various ministries of KRG and Baghdad.

Meetings and discussions with higher officials have resulted in UWA being listed as one of the preferred universities for Iraqi scholarship holders to undertake their higher degree studies overseas.

Collaboration in education and research with Africa

In April 2014, a three-day Australian-Africa Universities Network International Africa Forum, and Steering Group Meeting met to review progress, develop new project ideas and provide a forum for leading researchers and stakeholders from across both continents to network and collaborate.

IOA Industry Forum

Potential for food production in northern Western Australia

On 29 July 2014, IOA hosted its largest Industry Forum since the annual event began eight years ago.

The topic, *Potential for food production in northern Western Australia* could not have been more timely with WA Minister for Water and Forestry Hon Mia Davies announcing plans to help expand WA's agricultural sector in the West Kimberly region the day before.

Approximately 150 attendees listened to speakers discuss issues pertaining to irrigated agriculture, challenges and opportunities in the beef industry, cropping systems, agribusiness and sustainable development issues related to potential food production in northern WA.

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

Young Professionals in Agriculture

UWA graduates excelled again at this year's Young Professional in Agriculture Awards, claiming the top three awards as well as the prize for best presentation at the annual event, hosted by the Agriculture Institute of Australia (WA Division) and sponsored by the Department of Agriculture and food, WA (DAFWA).

UWA Agricultural Science graduate Kimberly Adams, an agronomist in Northam, took out the highest award for her presentation on stubble retention and the impact of soil water repellence in sandy soils.

Runner-up Nikki Dumbrell who graduated with first-class honours in Environmental and Natural Resource Economics presented on a range of carbon farming practices from the farmers' perspective, to identify which practices farmers are most likely –and least likely- to adopt and determine the underlying reasons for these preferences.

UWA graduates judged best young professionals in agriculture

Third place was claimed by Georgia Pugh, presented her research on the causes of 'dark cutting' beef which is classified as unfit for human consumption.

The best-presentation award was given to a fourth UWA graduate for his engaging talk on how he had used novel magnetic probes clamped to the leaves of individual wheat plants to monitor their water hydration status and explore the factors affecting a plant's capacity to maintain turgor.

For further information, see ioa.uwa.edu.au/__data/assets/pdf_file/0011/2591273/113161_IOA-Newsletter-Apri-14-final-WEB.pdf

Dowerin Field Days

IOA attended the 50th Dowerin Field Days on 27 and 28 August 2014, which saw a record 24,000 visitors.

The main message being communicated was Soil Quality and that a healthy soil has biological, chemical and physical properties that promote the health of plants, animals and humans whilst maintaining environmental quality.

There was considerable interest in the University's Farm Ridgefield near Pingelly, from farmers who were keen to hear about the latest research, and from high school students looking to pursue agricultural science at UWA.

For further information, see ioa.uwa.edu.au/__data/assets/pdf_file/0011/2591273/113161_IOA-Newsletter-Apri-14-final-WEB.pdf

Turf Research Program Open Day

Two Open Days were held at the UWA Turf Research Facility at Shenton Park in 2014, one in February and an inaugural winter Open Day in August.

The UWA Turf Research Program is assessing how effectively turfgrass growth and quality can be maintained on the current allocation, and what the implications are if the allocation is lowered.The Turf Industry was invited see how summer water allocations were affecting turfgrass quality in mid-winter.

Over 160 people attended the February event and 50 people attended the August event, with representatives from local government, schools, and other government departments. Attendees were able to inspect the turfgrass plots.

These events provide UWA staff with opportunities to discuss the implications of lowering water allocations with turfgrass managers in an informal setting, plus receive feedback from the industry which is funding the research in partnership with Horticulture Australia Limited (HAL).

Agricultural adjunct academics networking event

To acknowledge the contribution that adjunct academics in agricultural and related areas make in research and teaching, IOA hosted a networking event in October 2014. The event provided an opportunity for attendees to provide suggestions on how IOA and the University can enhance the partnership with adjuncts.

Turf Research Open Day, February 2014.

Visitors to IOA

IOA further strengthened its research links and collaborations with institutions and industry in Australia and nationally through hosting numerous national and international visitors, some of whom visited UWA for a full year.

The visitors included delegations and researchers from Lanzhou University and Tarim University in China, ICARDA, Jordan, Polish Academy of Science and Forschungszentrum Juelich, Germany.

For further information, see ioa.uwa.edu/publications/newsletters/previous-editions-ioa-news

Memoranda of Understanding

Institution	Date
Chinese Academy of Agricultural Sciences (CAAS)	February 2014
Worldwide Universities Network (WUN) Global Challenge Responding to Climate Change and the UK-USA Global Innovations Initiative	September 2014 Global Farm Platforms for Sustainable Ruminant Livestock: Statement of Intent
North-West Agriculture and Forestry University, Yangling, China	China-Australia Joint Research Centre for Ruminant Production
University of Agriculture, Faisalabad, Pakistan	Letter of MoU Extension, signed 3 December 2014
Syiah Kuala University, Banda Aceh, Indonesia	MoU signed 9 December 2014
International Crops Research Institute for the Semi Arid Tropics (ICRISAT)	Letter of MoU Extension, signed 9 December 2014

Awards and industry recognition for staff in 2014

Name	Award
Prof Ryan Lister	Frank Fenner Prize for Life Scientist of the Year 2014
Prof Roger Jones	Fellowship of the American Phytopathological Society
A/Prof Hari D Upadhyaya	Crop Science Society of America International Award 2014
Assoc/Prof Megan Ryan	Australian Research Council Future Fellowship
E/Prof Alan Robson	Western Australian Science Hall of Fame Inductee
Prof Ian Small	WA Scientist of the Year
Centre for Integrative Bee Research (CIBER)	Chevron Science Engagement Initiative of the Year
Dr Muhammad Farooq	Best Young Scientist Award from Higher Education Commission of Pakistan
Prof Kadambot Siddique	Winner of the Western Australian of the Year 2014 Professions Award www.news.uwa.edu.au/201406026719/awards-and-prizes/uwa-people-honoured-western-australian-year-awards
Dr Brenda Coutts	Winner of the AUSVEG National Awards for Excellence 2014 Researcher of the Year www.news.uwa.edu.au/201407026802/awards-and-prizes/national-recognition-uwa-research-student
Prof Roger Jones	Fellow of the American Phytopathological Society, 2014
Asst/Prof Marit Kragt	Award for Excellence in Honours Supervision at the UWA Faculty of Science Teaching Awards
Res/Assoc/Prof Ramin Rafiei	Viticulture and Oenology 2014 Science and Innovation Award for Young People in Agriculture. www.news.uwa.edu.au/201403066497/research/national-innovation-award-groung-breaking-water-stress-sensor
ARC Centre of Excellence in Plant Energy Biology	Winner of the Chevron Science Engagement Initiative of the Year. www.news.uwa.edu.au/201311226278/awards-and-prizes/arc-plant-energy-biology-wins-2013-wa-science-award
Prof Ryan Lister	Tall Poppy WA Award recognizing the brightest young scientists in WA www.news.uwa.edu.au/201311276286/awards-and-prizes/biological-scientist-named-states-tall-poppy
Prof Zed Rengel	Fulbright Scholar Award

Name	Award
Dr Mike Perring	Winner of Alan Robson Medal, awarded for research excellence in agriculture and related areas. Tile of his winning paper: "The Ridgefield Multiple Ecosystem Services Experiment: Can restoration of former agricultural land achieve multiple outcomesThe Ridgefield Multiple Ecosystem Experiment: Can restoration of former agricultural land achieve multiple outcomes?"
Asst/Prof Marit Kragt	Winners (as a team) of the 2013 AARES Quality of Research Communications Award. www.news.uwa.edu.au/201403066498/awards-and-prizes/uwa-team-wins-quality-research-communication-award
Prof Martin Barbetti	Elected Fellow of the Society for Rapeseed-Mustard Research of India for his contributions to Brassica research
Prof Roger Jones	Elected Fellow of The American Phytopathological Society for his many and significant contributions to plant virology

Research Projects and Research Training

New Research Projects 2014

Title	Funding Period	Funding Body	Supervisors
Molecular mechanisms underlying extensive replacement of phospholipids by galactolipids and sulfolipids in Hakea prostrata during leaf development	2014-2016	ARC Discovery Projects	W/Prof Hans Lambers, Assoc/Prof Patrick Finnegan, Dr Patrick Giavalisco
Revealing novel mechanisms conferring evolution of resistance to glufosinate and glyphosate in Eleusine indica	2014-2016	ARC Discovery Projects	W/Prof Stephen Powles, Assoc/Prof Qin Yu
Measuring protein turnover in vivo in plant mitochondria and chloroplasts to identify protease targets	2014-2016	ARC Discovery Projects	W/Prof Andrew Millar, Dr Shaobai Huang, Dr Adriana Pruzinska
Unique epigenetic states in plant stem cell niches for safeguarding genome integrity	2014-2016	ARC Discovery Projects	Prof Ryan Lister
Understanding the biological functions of the karrikin-responsive signaling system of plants in growth, development and responses to the environment	2014-2016	ARC Discovery Projects	Dr Steven Smith
Characterizing the regulators of mitochondrial biogenesis in Arabidopsis thaliana	2013-2017	ARC Future Fellowships	Dr Monika Murcha
Dissecting novel roles of succinate dehydrogenase in stomatal aperture and root elongation in plants	2013-2017	ARC Future Fellowships	Dr Shaobai Huang,
Evolutionary Adaptation of the Chemical Language of Nutrient Acquisition Strategies in Higher Plants	2014-2016	ARC Discovery Early Career Researcher Awards	Dr Margaretha van der Merwe
Round 2–Nitrate and Sulphate Rich Shrubs to Reduce Methane and Increase Productivity	2013-2015	CSIRO ex DAFF Carbon Farming Futures Filling Research Gap	Dr Hayley Norman, Prof Philip Vercoe, Prof Edward BarrettLennard, Assoc/Prof John Milton
Options for Improved Insecticide and Fungicide Use and Canopy Penetration in Cereals and Canola	2013-2015	GRDC	Dr Christian Nansen
Long Term No Till Farming Systems	2013-2015	GRDC	Dr Kenneth Flower
Phenotyping and Simulation of Barley Root Architecture for Edaphic Stress Adaption	2014-2015	Group of Eight DAAD German Research Cooperation	W/Prof Zed Rengel, Dr Johannes Postma, Dr Yinglong Chen

Title	Funding Period	Funding Body	Supervisors
ARC Centre of Excellence in Plant Energy Biology 2014 (CPEB2)	2014-2020	ARC Centres of Excellence	W/Prof Andrew Millar, Dr Barry Pogson, Prof Stephen Tyerman, Prof Ian Small, Prof James Whelan, A/Prof Justin Borevitz, Prof Ryan Lister, Dr Owen Atkin, Adj/Prof Rana Munns
Scientific Visits to Japan–Meeting future Australian pasture crop challenges: whole genome sequence of subterranean clover	2014	Australian Academy of Science	Dr Parwinder Kaur
PhysiTrace: Retailer Standard Compliance & Logistics and Implementation Plan	2014	Australian Pork Limited	W/Prof Garry Lee, W/Prof Roger Watling, Ms Heather Channon
Reassessing the Value & Use of Fixed Nitrogen	2013-2015	CSIRO ex GRDC	Assoc/Prof Michael Renton
Upskilling the Western Australian grains industry in disease surveillance for a more productive and biosecure future	2014-2016	COGGO	Prof Nancy Longnecker, Ms Dominie Wright
Synthetic Restorer Genes for Creation of Hybrid Wheat	2014-2015	Groupe Limagrain Vilmorin & Cie	Prof Ian Small
Organics Metals Salts Interactions in Food Safety & Environment Protection–Combined Experimental & Modelling Approach	2013-2014	Marie Curie Fellowship	Prof Davor Romic, W/Prof Zdenko Rengel
Round 2–Innovative Livestock Systems to Adapt to Climate Change & Reduce Emissions	2013-2015	Meat & Livestock Australia	Prof Philip Vercoe
CRC Impact Grain Industry Delivery Sites	2013-2016	Mingenew Irwin Group ex CRC Plant Biosecurity	Dr Christian Nansen
Enhancing Immune Competency to Improve Lamb & Weaner Survival	2013-2014	Murdoch University ex Meat & Livestock Australia	Prof Shimin Liu
Floor laying as welfare and economic issues in duck farming	2013-2016	Poultry CRC Ltd	A/Prof Dominique Blache, Prof Shane Maloney, A/Prof Ireneusz Malecki
Domestication of Kakadu Plum–Terminalia Ferdinandiana	2014-2016	Rural Industries Research & Development Corporation	Dr Liz Barbour, Ad/A/Prof Margaret Byrne, Mr Kim Courtenay, Dr Isabela Konczak, Mr Julian Gorman, Mr Cameron McConchie
Transitioning to Resilient Perennial Pasture Systems to Abate Greenhouse Gases & Sequester Carbon	2013-2016	Ternes Agricultural Consulting ex DAFF Carbon Farming Futures Action on the Ground	Prof Philip Vercoe
Development of Salinty Tolerant Wheat and Barley	2013-2015	University of Adelaide ex GRDC	Prof Ed BarrettLennard, W/Prof Timothy Colmer, Dr Roy Stuart
National Variety Trials Project (NVT)	2013-2014	University of Wollongong ex GRDC	Dr Aanandini Ganesalingam
Putting the Focus on Profitable Break Crop & Pasture Sequences in WA	2013	DAFWA ex GRDC	Assoc/Prof Michael Renton, Dr Arthur Diggle
Building Soil Carbon in Cropping Systems & Impact on Greenhouse Gas Emissions Using Cattle Feedlot Compost	2014-2017	WA Lot Feeders Association WALFA ex DAFF Carbon Farming Futures Action on the Ground	Dr Zakaria Solaiman, E/Prof Lynette Abbott, Mr Steve Jones

Title	Funding Period	Funding Body	Supervisors
UWA Led–Ancient Soils & Modern Land Use–A Challenge for Critical Zone Science International Workshop & Summer School	2013	Worldwide Universities Network WUN	Dr Matthias Leopold, Assist/Prof Deirdre Gleeson, Dr Gavan McGrath, Assoc/Prof Andrew Rate
Climate change in the media	2013	Worldwide Universities Network WUN	Assoc/Prof Meng Ji
Review Animal Welfare QA System in Europe	2013	Meat and Livestock Australia	W/Prof Graeme Martin
Pre Breeding in Annual Legumes	2013-2017	Department of Agriculture and Food WA (DAFWA) ex-Meat & Livestock Australia (MLA)	Prof William Erskine, Asst/Prof Janine Croser and Dr Parwinder Kaur
Distribution and predictors of benthic biodiversity	2014-2017	Western Australian Marine Science Institute (WAMSI)	A/Prof Kimberly Van Niel, W/Prof Gary Kendrick
Quantitative detection of *C. difficile* in piggery effluent treated in covered and uncovered anaerobic ponds and prevalence in biosolid byproducts (including land application and compost)	2014	Australian Pork Limited	Prof Thomas Riley
Design and evaluation of biosecurity surveillance systems	2014-2016	CRC Plant Biosecurity	Assoc/Prof Michael Renton, Prof Ben White, Dr Jacky Edwards, Dr John Wainer, Maggie Triska, John Botha, Dr Kevin Powell, Dr Cassandra Collins, Prof Roger Jones
National Taxonomy Research grant Program (NTGRP)–Diversity in the Triodia basedowii Ee.Pritz/ species complex and its implications for the evolution of the Australian arid zone biota	2014	Dept of Sustainability, Environment, Water, Population and Communities Australian Biological Resources Study	Benjamin Anderson
Tolerance of wheat genotypes to ion toxicities	2014-2015	GRDC	W/Prof Zed Rengel
Smart use of fertilizers to minimize and manage the risk of pest infestations in growing canola	2014-2016	GRDC	Assoc/Prof Christian Nansen
The Critical Zone Concept in the southern hemisphere – an international workshop		University of Sheffield, Pennsylvania State University	Asst/Prof Matthias Leopold
Biofuel and high value green chemicals from agricultural and silviculture non fodder residues	2014-2016	Queensland University of Technology (ex DIISR AISRF Grand Challenge Fund	Prof William Doherty, Dr Philip Hobson, Prof Sagadevan Mundree, Dr Victoria Haritos, Assoc/Prof Vishnu Pareek, Dr Tony Vancov, W/Prof Dongke Zhang
Visit to duck farms in Netherlands that use vencomatic nesting system	2014	Poultry CRC Ltd	Assoc/Prof Ireneusz Malecki
Modelling the spread of Skeletal Weed in WA	2014	DAFWA	Assoc/Prof Michael Renton

Title	Funding Period	Funding Body	Supervisors
Safeguarding Honeybees - increasing parasite effectiveness using nano technology	2014-2017	Australian Research Council (ARC) Linkage Projects	Prof Boris Baer, Dr Iyer Swaminatha, Dr L Killugudi, Dr William Bosch
Gene identification & functional characterization for metabolism based herbicide resistance in lolium rigidum	2014-2017	ARC Linkage Projects	W/Prof Stephen Powles, Assoc/Prof Qin Yu, Dr Roland Beffa
Characterisation of soil microbial interactions for increased efficacy of herbicides using novel fertiliser management practices	2014-2017	ARC Linkage Projects	W/Prof Andrew Whiteley, E/Prof Lyn Abbott, Dr Abul Hashem Mr Paul Storer
Bushfire and Natural Hazards CRC	2014-2017	CRC	W/Prof David Pannell
Novel business structures for adaptation to a changing climate	2013/14 to 2015/16	DAFF	Prof Ross Kingwell
Building better brassicas–understanding disease resistance mechanisms across the brassicaceae'-	2014-2017	ARC Future Fellowships	Assoc/Prof Jacqueline Batley
Pre breeding in annual legumes	2013-2016	DAFWA ex MLA	Prof William Erskine, Asst/Prof Janine Croser and Dr Parwinder Kaur
Characterising root traits for efficient water and nutrient acquisition in barley.	2015	UWA Research Collaboration Awards -Pennsylvania State University	Dr Yinglong Chen, W/Prof Zed Rengel and Hackett Prof Kadambot Siddique
Crops for a phosphorusscarce future: plant adaptation to fluctuating phosphorus availability	2014-2017	ARC Future Fellowships	Assoc/Prof Megan Ryan
Making clover pastures permanently resistant to Phytophthora root disease	2014-2017	Australian Wool Innovation Ltd	W/Prof Martin Barbetti
Innovation of Farms 2013 to 2018 Round 1–Maximising Benefit from Crop Residues–Practical Stubble Retention Practices in Mixed Farming Systems of WA	2014-2016	Blackwood Basin Group ex South West Catchments Council	Dr Zakaria Solaiman and Felicity Willett
Use of Chemicals to Increase Frost Tolerance in Australian Crops	2014-2015	GRDC	W/Prof Stephen Powles, A/Prof Roberto Busi, A/Prof Kenneth Flower and Prof Jack Christopher
Development of Molecular Markers for Application in Australia Canola Breeding	2014	NSW DPI ex GRDC	A/Prof Sheng Chen, Hackett Prof Kadambot Siddique and W/Prof Wallace Cowling
Provision of Advanced Statistical Advice on Genetic Analysis of Canola Breeding Data and Optimum Design of Trials	2012-2013	University of Wollongong ex NPZ Australia	A/Prof Katia Stefanova
Introducing Diverse Perennial Pastures into Potato/ Pasture Rotations to Improve Soil Health and Pasture and Potato Yield and Quality	2014-2017	Water Corporation ex South West Catchments Council	Dr Zakaria Solaiman, Kathy Dawson and Deb Archdeacon
Evaluation of musa acuminata subsp. Malaccensis for resistence to Fusarium wilt of banana	2014	UWA-UQ Partnership Research Collaboration Award	Assoc/Prof Jacqueline Batley
Characterising genes for wheat quality	2014	UWA-UQ Partnership Research Collaboration Award	Prof David Edwards

New PhD research students

Ten students commenced their postgraduate studies in agriculture and related areas at UWA in 2014.

Name	Topic	School	Supervisor(s)	Funding Body
Anna Aryani Amir	Effects of plant extract and plant secondary compounds (PSC) from grazing shrubs on in vitro oocytes maturation, embryo development and ovulation rate in ewes.	Animal Biology and IOA	Prof Graeme Martin, Assoc/Prof Dominique Blache	Self-funded
Karen Frick	Genomic approaches to improve narrow-leafed lupin as a human food	Plant Biology, IOA and CSIRO	Prof Kadambot Siddique, Dr Rhonda Foley (CSIRO), Asst/Prof Lars Kamphuis (CSIRO and IOA)	UPA and UWA safety-net top-up scholarship
Diana Prada	Market based instruments for conservation preferably in developing countries	Agricultural and Resource Economics and IOA	Asst/Prof Marit Kragt, Prof Michael Burton	Australian Postgraduate Award UWA Safety Net Top-up Scholarship
David Rees	Farmers' engagement in the development of innovation	Agricultural and Resource Economics and IOA	Asst/Prof Ram Pandit, Prof Ben White, Asst/Prof Maksym Polyakov	Self-funded
Thayse Figueiredo Nery	Optimal land-use change to increase water quality, quantity and biodiversity outcomes	Agricultural and Resource Economics and IOA	Prof Ben White Assoc Prof Steven Schilizzi	Science Without Borders - Brazilian federal government
Ali Mohammed Oumer	Incentives for Successful Livelihood Adaptation to Agricultural Risks in Maize Farming System in Ethiopia: Pathways to Sustainable Agricultural Intensification	Agricultural and Resource Economics and IOA	Assoc Prof Atakelty Hailu Assist Prof Amin Mugera	Australian Centre for International Agricultural Research (ACIAR)
Tuan Trung Pham	Improving agricultural co-operative models of production and business practice for better member livelihoods in developing countries. An application to An Giang Province, Vietnam.	Agricultural and Resource Economics and IOA	Assoc/Prof Steven Schilizzi, Assoc/Prof Md. Sayed Iftekhar, W/Prof Tim Mazzarol, Assist/Prof Elena Mamouni Limnios	AusAid Scholarship
Seyedehmahsa Mousaviderazmahalleh	Ancient polyploidy in the *genus Lupinus*	Plant Biology and IOA	Assoc/Prof Matthew Nelson & W/Prof William Erskine	Endeavour Postgraduate Scholarship
Yaseen Kahlil	Conservation Agriculture in Drylands	Plant Biology and IOA	Dr Ken Flower Hackett Prof Kadambot Siddique, Dr Phil Ward, Dr Stephen Loss and Dr Colin Piggins	John Alwright Fellowship, ACIAR
Ahmed Rashid Sukkar Alsharmani	Dynamics of arbuscular mycorrhizal fungi in perennial and annual pasture	School of Earth and Environment and IOA	E/Prof Lyn Abbott and Dr Zakaria Solaiman	Higher Committee for Education Development in Iraq, Government of Iraq

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Education, Outreach and Technology Exchange

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Deputy Leader: Position vacant

Executive Management Board (EMB)

The Institute is governed by its Executive Management Board with the Deputy Vice Chancellor (Research) as Chair. The Board consists of representatives from relevant schools within UWA's Faculty of Science and other faculties, the IOA Director and on a rotational basis a representative from relevant Research Centres.

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The IAB provides the Institute with industry interaction, advice and feedback. IAB members represent a cross-section of agricultural industries and natural resource management areas.

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Mr Philip Gardiner
Farmer

Mr Dawson Bradford
Farmer, Chair of Lambex, and Chairman, WAMMCO

Mr Terry Hill
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Prof Tony O'Donnell
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Mr Rod Birch
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Dr Jim Fortune
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Dr Michael Robertson
CSIRO, Deputy Chief, Ecosystem Sciences

Mr Shane Sander
Founder of Agvise Management Consultants

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UWA IOA Publications 2014

Refereed journals

1. Abbott LK, Lumley SE (2014) Mycorrhizal Fungi as a Potential Indicator of Soil Health *Mycorrhizal Fungi: Use In Sustainable Agriculture And Land Restoration* **2**:1-31
2. Abdullah AS (2014). Minimum tillage and residue management increase soil water content, soil organic matter and canola seed yield and seed oil content in the semiarid areas of northern Iraq. *Soil & Tillage Research* **144**: 150-155.
3. Adhikari KN, Khan TN, Stefanova K and Pritchard I (2014). Recurrent breeding method enhances the level of blackspot (*Didymella pinodes* (Berk. & Blox.) Vestergr.) resistance in field pea (*Pisum sativum* L.) in southern Australia. *Plant Breeding* **133**: 508-514.
4. Ahmad F, Maqsood MA, Aziz T, Cheema MA (2014) Water soluble iron (Fe) concentration in alkaline and calcareous soils influenced by various Fe sources *Pakistan Journal Of Agricultural Sciences* **51**(2):417-421
5. Ahmad I, Khaliq I, Khan AS and Farooq M (2014). Screening of spring wheat (*Triticum aestivum* L.) genotypes for drought tolerance on the basis of seedling traits. *Pakistan Journal of Agricultural Sciences* **51**: 367-372.
6. Alharby HF, Colmer TD and Barrett-Lennard EG (2014). Salt accumulation and depletion in the root-zone of the halophyte *Atriplex nummularia* Lindl.: influence of salinity, leaf area and plant water use. *Plant and Soil* **382**: 31-41.
7. Alqaisi O, Hemme T, Latacz-Lohmann U, Susenbeth A (2014) Evaluation of food industry by-products as feed in semi-arid dairy farming systems: the case of Jordan *Sustainability Science* **9** (3):361-377
8. Aziz T, Sabir M, Farooq M, Maqsood MA, Ahmad HR, Warraich EA (2014) Phosphorus Deficiency in Plants: Responses, Adaptive Mechanisms and Signaling *Plant Signaling: Understanding The Molecular Crosstalk* 355
9. Al-Saady NA, Nadaf SK, Al-Subhi AS, Al-Hinai SA, Al-Farsi SM, Al-Habsi KM, Esechie HA and Siddique KHM (2014). Multicrop legume germplasm collection in Oman**.** *Int. J. Agric. Biol.* **16** (2): 231-241.
10. Anderson WK, McTaggart RM, McQuade NC, Carter D, Overheu T, Bakker D and Pletzer S (2014). An approach to crop yield improvement through diagnostic systems research in a winter-dominant rainfall environment. *Crop and Pasture Science* **65** (9): 922-933.
11. Ashworth MB, Walsh MJ, Flower KC and Powles SB (2014). Identification of the first glyphosate-resistant wild radish (*Raphanus raphanistrum* L.) populations. *Pest Manag Sci* **70** (9): 1432-1436.
12. Aryamanesh N, Zheng Y, Byrne O, Hardie DC, Al-Subhi AM, Khan T, Siddique KHM and Yan G (2014). Identification of genome regions controlling cotyledon, pod wall/ seed coat and pod wall resistance to pea weevil through QTL mapping. *Theoretical and Applied Genetics* **127**: 489-497.
13. Awasthi R, Kaushal N, Vade V, Turner NC, Berger J, Siddique KHM and Nayyar H (2014). Individual and combined effects of transient drought and heat stress on carbon assimilation and seed filling in chickpea. *Functional Plant Biology* **41**: 1148-1167.
14. Ayalew H, Ma X and Yan G (2014). Screening wheat (*Triticum spp*) genotypes for root length under contrasting water regimes: potential sources of variability for drought resistance breeding. *Journal of Agronomy and Crop Science* **201** (3):189-194
15. Aziz T, Finnegan PM, Lambers H and Jost R (2014)**.** Organ-specific phosphorus-allocation patterns and transcript profiles linked to phosphorus efficiency in two contrasting wheat genotypes. *Plant, Cell and Environment* **37**: 943-960.
16. Aziz A, Wahid A and Farooq M (2014). Leaf age and seasonality determines the extent of oxidative stress and induction of antioxidants in lemongrass. *Pakistan Journal of Agricultural Sciences* **51**: 659-664.
17. Bailey-Serres J and Colmer TD (2014). Plant tolerance of flooding stress - recent advances. *Plant, Cell & Environment* **37**: 2211-2215.
18. Barbetti MJ, Banga SK, Fu TD, Li YC, Singh D, Liu Sy, Ge XT and Banga SS (2014). Comparative genotype reactions to *Sclerotinia sclerotiorum* within breeding populations of *Brassica napus* and *B. juncea* from India and China. *Euphytica* **197**: 47-59.
19. Barbetti MJ and You MP (2014). Opportunities and challenges for improved management of foliar pathogens in annual clover pastures across southern Australia. *Crop and Pasture Science* **65:** 1249-1266.
20. Barrow NJ, Debnath A (2014) Effect of phosphate status on the sorption and desorption properties of some soils of northern India *Plant And Soil* **378**(1-2):383-395
21. Barton L, Thamo T, Engelbrecht D and Biswas W (2014). Does growing grain legumes or applying lime cost effectively lower greenhouse gas emissions from wheat production in a semi-arid climate? *Journal of Cleaner Production* DOI: 10.1016/j.jclepro.2014.07.020.
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Acronyms

AAUN	Australia Africa University Network
ACPFG	Australian Centre for Plant Functional Genomics
ACIAR	The Australian Centre for International Agricultural Research
AHRI	The Australian Herbicide Resistance Initiative (at UWA)
AISRF	Australia-India Strategic Research Fund
ANU	Australian National University
APA	Australian Postgraduate Award
ARC	Australian Research Council
AusAID	Australian Government's overseas aid program
AWI	Australian Wool Innovation Ltd
BPS	Black pod syndrome
BYMV	Bean yellow mosaic virus
CAAS	The Chinese Academy of Agricultural Sciences
CAP	covered anaerobic pond
CBH	Corporate Bulk Handling Group (company)
CDAE	Centre for Dryland Agricultural Ecosystems
CGE	Clean, green, and ethical
ClYVV	Clover yellow vein virus
CLIMA	Centre for Legumes in Mediterranean Agriculture (at UWA)
COGGO	Council of Grain Growers Organisation
CSBP Ltd	The Chemicals and Fertilisers business units of Wesfarmers Chemicals, Energy and Fertilisers, a division of Wesfarmers Limited
CSIRO	Commonwealth Scientific & Industrial Research Organisation
CZO	Critical Zone Observatory
DAAD	German Academic Exchange Service
DAFFQ	Department of Agriculture, Fisheries and Forestry, Queensland
DAFWA	Department of Food and Agriculture Western Australia
DH	Double Haploid
DFAT	Department of Foreign Affairs and Trade (incorporates AusAID)
EDM	Edible dry matter
FCR	Fusarium crown rot
FGS	Fast generation system
FZJ	Forschungszentrum Jüelich
GHG	Greenhouse Gas
Go8	Group of Eight
GPS	Global positioning system
GRDC	Grains Research and Development Corporation
HAL	Horticulture Australia Limited
HarMV	Hardenbergia mosaic virus
IAS	Institute of Advanced Studies (at UWA)
IAPM	Institute of Applied Plant Nutrition
ICARDA	International Centre for Agriculture Research in the Dry Areas, Syria
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ILZ	Intensive Landuse Zone
IMK-IFU	Institute of Meteorology and Climate Research, Atmospheric Environmental Research
IOA	The UWA Institute of Agriculture
KRG	Kurdish Regional Governorate
LDD	Long-distance dispersal
LZU	Lanzhou University, China
MAF	Timor-Leste Ministry of Agriculture and Fisheries
MLA	Meat and Livestock Australia
MoU	Memorandum of Understanding
NILs	Near isogenic lines
NHMRC	National Health and Medical Research Council
NSCP	National Soil Carbon Program
NLL	Narrow-leafed lupin
NLMP	national Livestock Methane Program
NGO	Non-governmental organisations
NGS	Next generation sequencing
NSP	Non-starch polysaccharides
NSW-DPI	New South Wales Department of Primary Industries
NPZ-Lembke	Norddeutsche Pflanzenzucht Hans-Georg Lembke KG, Germany
NVT	National Variety Trials
PCR	Polymerase chain reaction
PFRNZ	New Zealand Plant and Food Research Limited
PGB	Plant Genetics and Breeding (at UWA)
PGIBSA	Phylloxera and Grape Industry Board of South Australia
PSbMV	Pea seed-borne mosaic virus
PVY	Potato virus Y

QA	Quality assurance
QTL	Quantitative trait locus
RELRP	Reducing Emissions from Livestock Research Program
RIRDC	Rural Industries Research and Development Corporation
RMIT	Royal Melbourne institute of Technology
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
SIRF	UWA Scholarships for International Research Fees
SoL	Seeds of Life (project in Timor-Leste)
SOM	Soil organic matter
TuMV	Turnip mosaic virus
UASM	University of Applied Sciences Mannheim
USDA	United States Department of Agriculture
UWA	The University of Western Australia
UWiN	Underground wireless sensor networks
VIC-DPI	Department of Environment and Primary Industries, Victoria
VPD	Vapour pressure deficit
WAIMR	Western Australian Institute of Medical Research
WAMMCO	Western Australian Meat Marketing Co-operative
WANTFA	Western Australian No-Tillage Farmers Association
WSMV	Wheat streak mosaic virus
WUN	Worldwide Universities Network
ZYMV	Zucchini yellow mosaic virus

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