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GRDC

GROUNDCOVER SUPPLEMENT

ANALYTICS, DATA AND PHENOMICS

Digital technologies transforming grains RD&E

By Dr John Rivers and Tom Giles

Enabling Technologies – manager and senior manager, GRDC

WHY

Advances in data collection, management, and analytics technologies are contributing to a 'digital agriculture revolution' in the Australian grains industry. The May–June edition of *GroundCover*™ *Supplement* described how GRDC is investing in the digital agriculture revolution on-farm, combining sensing and analytics to automate tasks and decisions. In this *GroundCover*™ *Supplement*, we explore GRDC's investments in the foundational capabilities and resources needed to unlock digital agriculture opportunities in the research, development, and extension (RD&E) sector.

WHAT

We need large-scale analytics capacity to support grains RD&E. Applying analytics to data leads to insights, increased productivity and, ultimately, better RD&E outcomes.

Analytics for the Australian Grains Industry (AAGI) is a five-year strategic partnership between GRDC, Curtin University, University of Queensland and University of Adelaide to harness analytics to improve the Australian grains industry's profitability and global competitiveness.

Featured on pages 3–5, AAGI provides our industry with substantial capacity and capability across statistics, machine learning, data fusion and other data sciences. This *GroundCover*™ *Supplement* has case studies of AAGI's work improving breeding selections (page 7), uncovering how environmental factors influence disease incidence (page 9), and analysing the efficacy of agronomic management at a sub-paddock scale (page 6).

Innovations in Plant Variety Testing in Australia (INVITA) is another major investment in analytics and data (pages 12-13). Over the past four years, it has intensively characterised selected National Variety Trials (NVT) sites and has used this data to develop analytics for better-interpreting field trial results.

The May–June *GroundCover*™ *Supplement* highlighted efforts to collate on-farm data and make it available for automated tasks and decision-making on-farm. This *GroundCover*™ *Supplement* highlights our parallel efforts to make RD&E data findable and available for further innovation through GRDC's recently launched Data Catalogue (page 23).

GRDC's investments in phenomics are also featured in this *GroundCover*™ *Supplement* and reflect our approach to digital agriculture investment. They are collecting quantitative crop plant observational datasets and applying analytics to support crop genetic improvement and agronomic RD&E. The centrepiece of GRDC's phenomics portfolio is its co-investment in the multi-million-dollar Australian Plant Phenomics Network (page 10). This co-investment will substantially improve the grains industry's access to high-end phenotyping infrastructure and capability.


Photo: APPN

APPN drone with state-of-the-art sensor package.

HOW

Data analytics and digital technologies are transforming industry sectors worldwide. It should be no surprise our digital agriculture investments use diverse talent and technologies to realise their intended outcomes. Capacity building in digital agriculture and attracting people with applicable skills into the grains industry will be crucial in the coming years. Examples of capacity building in our investments are also highlighted here (pages 20-21).

Given their foundational nature, these investments must also coordinate and collaborate across many organisations within the grains industry to ensure foundational resources and capabilities have broadest impact; that is, best bang for buck. The investments in this *GroundCover*™ *Supplement* reflect the diverse talent and resources we access and the breadth of organisations we work with to unlock the research and innovation opportunities across analytics, data and phenomics. ☐

More information: Dr John Rivers, john.rivers@grdc.com.au; Tom Giles, tom.giles@grdc.com.au

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

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GROUNDCOVER*™ *SUPPLEMENT edited by Dr Sue Knights

COVER IMAGE: Innovation in the grains industry is boundless, stemming from the early hand tools to applications of sophisticated digital technologies.

PHOTO: stock.adobe.com montage Tim Claeys

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Analytics to power grains decisions


Photo: 123RF

GRDC is boosting its commitment in big data and analytics through the investment 'Analytics for the Australian Grains Industry'.

The era of data-driven decision-making is opening new pathways for increasing industry profitability

KEY POINTS

- The grains sector is evolving into a data-driven industry that requires rigorous analytical capabilities to convert raw data into valuable insights for growers and the broader industry
- 'Analytics for the Australian Grains Industry' is a GRDC data science investment harnessing cutting-edge statistics, machine learning, data fusion and analytics to improve the speed, accuracy and efficiency of RD&E for Australian growers

The grains sector is undergoing an immense transformation, evolving into an industry driven by data.

Current and future research, development and extension (RD&E) projects require a rigorous, data-driven approach. Statistical and analytical capabilities are critical for converting raw data into meaningful knowledge for growers and the broader grains industry.

For more than a decade, GRDC has identified the value of utilising data science and statistics to benefit the Australian grains industry by investing in biometrics. The foundational work of GRDC's $23.8 million 'Statistics for the Australian Grains Industry 3' (SAGI3) investment ran from 2016 to 2023. SAGI3 provided statistical expertise to more than 210 GRDC investments totalling more than $490 million.

As a result of these investments, growers now benefit from better germplasm selections in pre-breeding programs, clearer research-driven agronomic recommendations, and tools that use data to support on-farm decision-making.

GRDC is now building on this strong foundation to unleash the potential of a combination of cutting-edge statistics, machine learning, data fusion and analytics for Australian grain growers.

Analytics for the Australian Grains Industry (AAGI) is a flagship GRDC investment, a five-year strategic partnership aimed at harnessing analytics to drive the grains sector's profitability and global competitiveness.

GRDC has committed $36 million over five years to AAGI, which complements a $56 million co-investment from the initiative's three strategic partners at Curtin University, the University of Queensland and the University of Adelaide.

AAGI creates a significant opportunity for Australian growers to be world leaders in analytics-driven decision-making to drive efficiency and precision in RD&E and support farm enterprise risk management.

AAGI's mission is to use analytics in grains RD&E to help Australian grain growers become more profitable and globally competitive. It will do this through:

- a collaborative investment partnership model with end-user focused innovation, greater cash and in-kind leverage, and international profile and scale; and
- building human capacity with analytics skills required to meet the needs of the Australian grains industry and RD&E sector.

AAGI is building a national ecosystem, working with academic and industry partners, directly growing substantial capacity in the grains RD&E analytics workforce, with investment to support the equivalent of 49 full-time researchers and 48 higher degree research students as well as delivering training and workshops across the country.

This increased capacity will broaden analytics capabilities, allow for more investment in high-priority research, and attract additional intellectual property, investment and expertise from the commercial sector and other parties.

AAGI is planning research and development to support:

- utilisation of satellite and drone sensing technologies for digital agriculture applications;
- simulation and analytical methods for supporting on-farm and supply chain decision-making;
- research in machine autonomy/intelligent systems, aligned with GRDC's separate Grain Automate investments;
- advanced phenotyping methods, including automated image analysis and segmentation;
- new statistics, machine learning, and bioinformatics approaches to support pre-breeding for biotic and abiotic traits; and
- understanding of the interaction of crop genetics, environmental variation, agronomic management, and biotic (for example, pest, weed, disease) pressures. ☐

GRDC Codes UOQ2301-010OPX, UOA2301-005OPX, CUR2210-005OPX

More information: Dr Nathan O'Callaghan, nathan.ocallaghan@curtin.edu.au

Analytics for the Australian Grains Industry

AAGI is committed to harnessing the power of statistics, machine learning, datafusion and analytics to benefit grain growers. Its mandate is to enable analytics-driven decision-making, empowering growers to enhance profitability by reducing input costs, minimising risks, optimising yields, enhancing soil health and achieving more sustainable agricultural practices.

AAGI
Analytics for the Australian Grains Industry

MISSION

Use analytics in grains RD&E to help Australian grain growers to be more profitable and globally competitive.

Develop and support a collaborative investment partnership model with end-user-focused innovation.

Deliver human capacity with analytics skills required to meet the needs of the Australian grains industry and RD&E sector.

ANALYTICS-DRIVEN DECISION MAKING

AAGI is an investment of GRDC. It is led by strategic partners Curtin University, the University of Queensland and the University of Adelaide.


Dr Nathan O'Callaghan, director

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Curtin University

Project lead: Professor Mark Gibberd
Deputy lead: Dr Julia Easton, Professor Adam Sparks
Strengths: spatial modelling, on-farm analytics, bioinformatics, plant-pathogen analytics
New capabilities: machine learning, AI, computer vision, optimisation, agribusiness, data fusion

The University of Adelaide

Project lead: Dr Julian Taylor
Deputy lead: Dr Olena Kravchuk
Strengths: biometry, statistical genomics, sampling, computing

The University of Queensland

Project lead: Professor Scott Chapman
Deputy lead: Emeritus Professor Kaye Basford
Strengths: machine learning, AI, computer vision, data analytics pipelines, big data computing, analytical plant breeding


Prof Mark Gibberd


Dr Julia Easton


Prof Adam Sparks

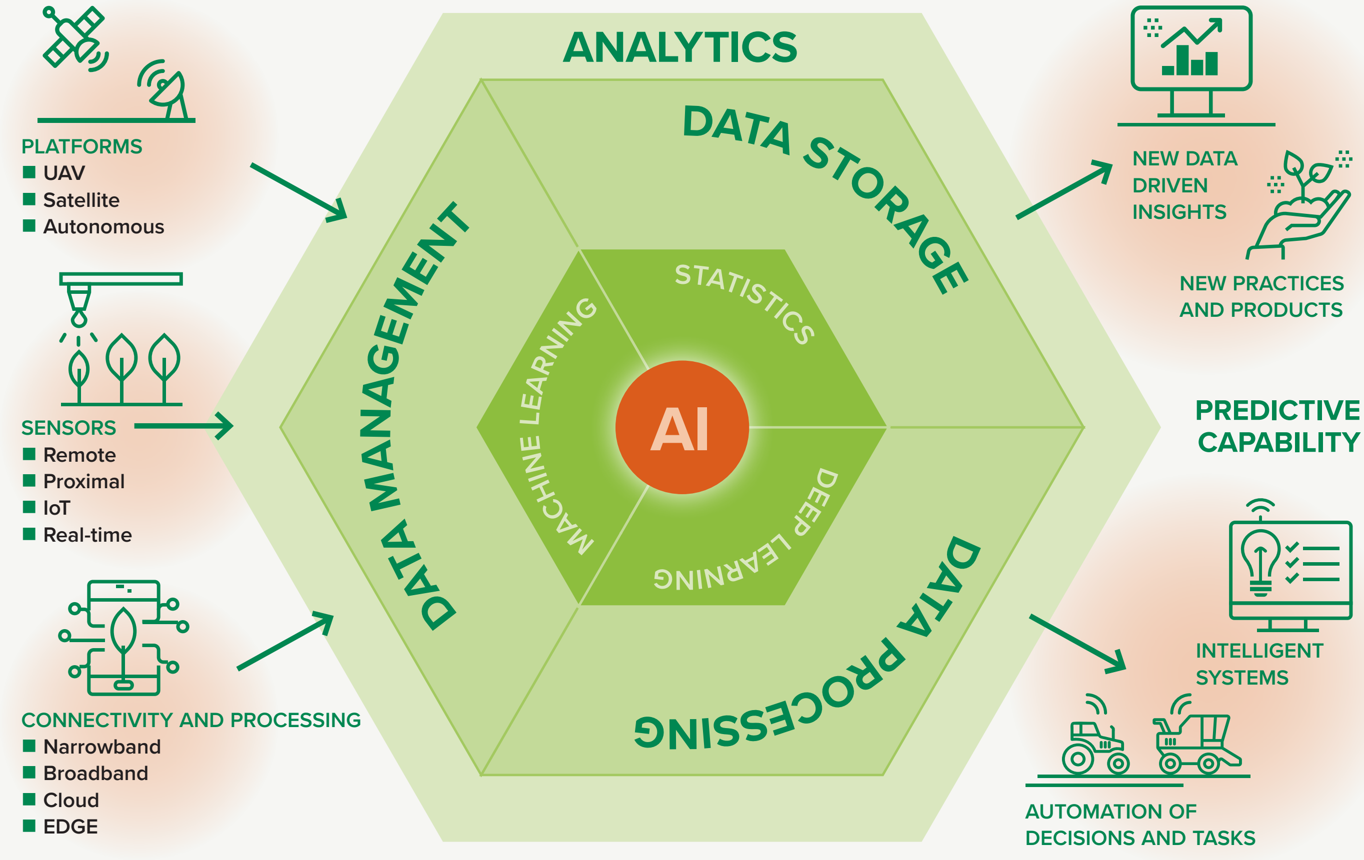

Dr Julian Taylor


Dr Olena Kravchuk


Prof Scott Chapman


Prof Kaye Basford

ANALYTICS-DRIVEN DECISION MAKING



PLATFORMS
- UAV
- Satellite
- Autonomous

SENSORS
- Remote
- Proximal
- IoT
- Real-time

CONNECTIVITY AND PROCESSING
- Narrowband
- Broadband
- Cloud
- EDGE

NEW DATA DRIVEN INSIGHTS

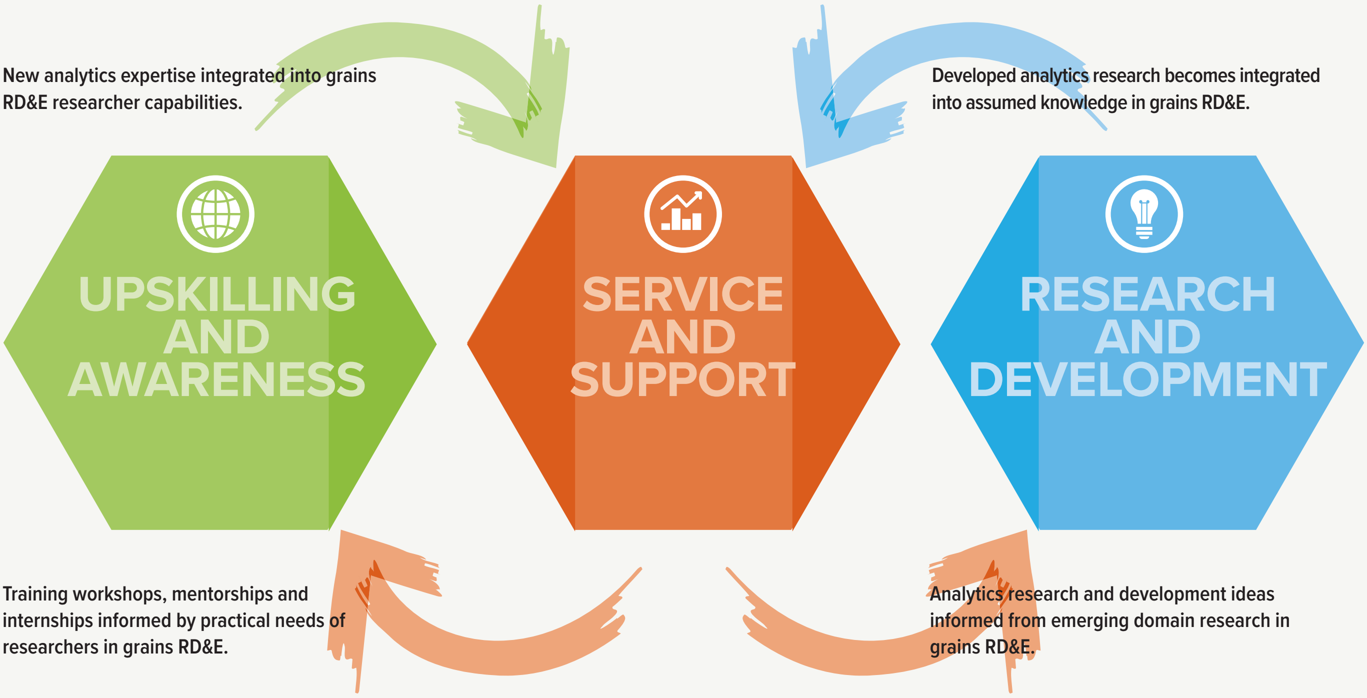
NEW PRACTICES AND PRODUCTS

PREDICTIVE CAPABILITY

INTELLIGENT SYSTEMS

AUTOMATION OF DECISIONS AND TASKS

AAGI PROGRAMS AND IMPROVEMENT CYCLES



New analytics expertise integrated into grains RD&E researcher capabilities.

Developed analytics research becomes integrated into assumed knowledge in grains RD&E.

Training workshops, mentorships and internships informed by practical needs of researchers in grains RD&E.

Analytics research and development ideas informed from emerging domain research in grains RD&E.

Big data approach improves on-farm trial insights

Spatial analysis within a paddock helps to increase the effectiveness of on-farm trials by improving their placement and the subsequent selection of treatment options

By Dr Julia Easton and
Dr Arnold Salvacion

Centre for Crop and Disease Management,
Curtin University

Photo: Jesse Helliwell

Members of the Curtin for Agribusiness Profitability Initiative of CCDM, viewing maps at the Data Visualisation Lab at the Pawsey Supercomputer facility.

■ The extent of spatial variability when measuring production performance poses significant challenges for efficient and sustainable crop management.

While precision agriculture tools such as yield maps, variable-rate technology (VRT), remote sensing and data analysis to manage variability are making input decisions more accurate, there remain shortcomings and a need for developing new statistical and analytics tools. VRT maps are often hand-drawn based on historical yield maps and grower or adviser experience. This can lead to unexpected results owing to the complexity of the intersection between soil, climate and agronomy.

With GRDC support, through Analytics for the Australian Grains Industry (AAGI) and with the Food Agility CRC's Agri-analytics Hub, researchers at Curtin University's Centre for Crop and Disease Management are addressing this with NGIS, Farmanco and the Department of Primary Industries and Regional Development. Researchers have developed spatial analysis tools that can account for the natural variation in a paddock. This has been shown to lift grower confidence in the use of VRT maps, which can be further supported through the generation of meaningful results from paddock-scale strip trials.

METHODS

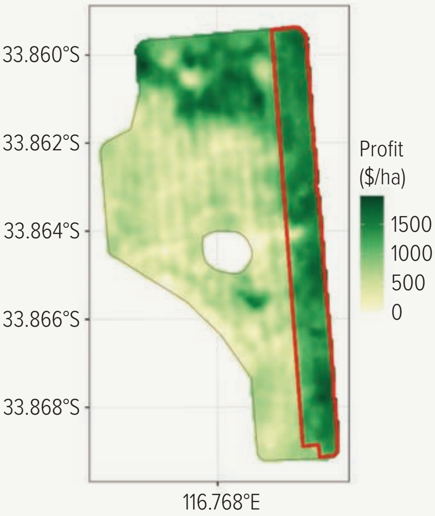
Through a co-design approach, working with growers and their advisers, researchers identify areas within paddocks that are underperforming and then locate and design experiments to understand what is affecting the underperformance.

Researchers begin by visualising yield patterns and categorising them according to performance, using historical yield data and algorithms for data ingestion and interpolation. Through discussions with the grower and their advisers, they co-design an on-farm experimental strip trial in the optimal area of the paddock. Statistical methods and spatial analysis algorithms are then used to analyse large datasets and predict the crop response and profitability of treatments within the paddock.

STEPS TO APPLY A BIG-DATA APPROACH TO ON-FARM TRIALS

1. **Visualise** paddock data in map format (yield, NDVI, protein, elevation, EM38 etc.) cleaned and interpolated for multi-season comparison.
2. **Analyse** patterns of yield within paddock to understand spatial variability, yield stability, probability of exceeding break-even yield, simple profitability analysis and locate strip trials.
3. **Experiment** with strip trials designed and located to encompass spatial variability and to understand yield constraints.
4. **Predict** return on investment and risk, considering current crop performance and future climate projections.

Figure 1: Map of profit ($/ha) for a wheat crop grown in 2021 following a Plozza plough soil amelioration treatment strip (summer 2019-20) and a canola crop (2020 season) at Qualeup, WA.
The treatment strip runs north to south (outlined in red). Trial conducted by DPIRD (Alice Butler, Bindi Isbister, Gaus Azam projects).



The team has developed these methods for fertiliser trials and is now developing them for analysing soil amelioration trials (Figure 1). These on-farm trials draw on geographically weighted regression analysis to determine spatially varying responses to fertiliser in a map format.

While it has limitations, particularly in areas where crop yields are reaching the maximum, it can otherwise be used to determine which sections of the paddock are responding to fertiliser treatments. The development of analytical capability and the usefulness of research outputs have been fast-tracked through our co-design approach with growers. ☐

GRDC Codes CUR2210-005OPX, DAW1902-003RTX, DAW1901-006RTX

More information: Dr Julia Easton, 08 9266 1727, julia.easton@curtin.edu.au

Analytics identifying valuable new genetics

Collaborative international efforts underpinned with the latest analytics are boosting the breeding pipeline for Australian cereal varieties

Photo: courtesy Vivi Arief

With a PhD in plant breeding and quantitative genetics, Dr Vivi Arief brings insights to the analytical support through the Analytics for Australian Grains Industry initiative to the CAIGE program.

■ Australian plant breeders require access to diverse genetic resources to develop new and improved crop varieties with desirable characteristics for both yield and disease resistance for evolving Australian farming systems and markets.

Collaborations with institutions such as the International Maize and Wheat Improvement Center (CIMMYT) in Mexico and the International Center for Agricultural Research in the Dry Areas (ICARDA) in Morocco have partly met this need for Australia.

Established in 2007, the GRDC-supported project – CIMMYT Australia ICARDA Germplasm Evaluation (CAIGE) – selects, imports and evaluates bread wheat and durum lines in Australia.

Since 2013 it has included bread and durum lines from ICARDA as well as barley. Cutting-edge analytics are now more precisely targeting lines of value.

The program maximises value for Australian growers by leveraging international investment in wheat and barley breeding. Coordinated by the University of Sydney, it comprises two components – wheat, led by the University of Sydney's Professor Richard Trethowan, and barley, led by Associate Professor Mark Dieters (formerly from the University of Queensland). Dr Julie M Nicol coordinates the CAIGE program, with Dr Amit Singh managing the website and database.

CAIGE is a multi-stakeholder project with two international partners, nine Australian commercial breeding companies and eight public sector institutions, all benefiting from the program.

PROCESS

Dr Nicol says Australian breeders evaluate and select promising lines for specific traits during visits to international centres – CIMMYT in Mexico (for bread and durum wheats) and ICARDA in Morocco (for bread, durum wheat and barley). The lines are inspected in the field, and the data (phenotypic and genotypic) is evaluated in collaboration with international scientists.

"Selected bread wheat lines are also phenotyped using one of the global phenotyping platforms to narrow selections for Australian evaluation," Dr Nicol says.

"Imported lines undergo genotyping and seed increase with Agriculture Victoria-Australian Grains Genebank in Horsham, and are then multiplied post-quarantine at the University of Sydney in Narrabri.

"Final selections are made based on additional data from the international centres and then – in collaboration with commercial breeding programs – yield trials are planted across the Australian grainbelt and assessed for disease resistance with our public partners."

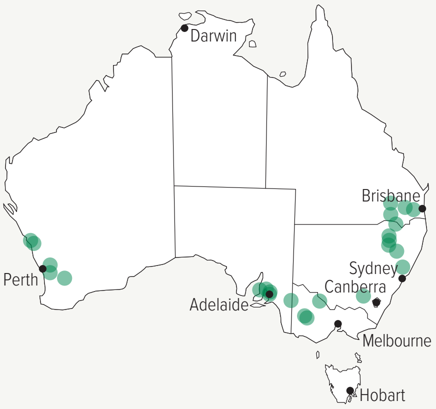
Statistical evaluation of the field trials was provided in the past by the GRDC-supported Statistics for the Australian Grains Industry and in the past year by GRDC's Analytics for the Australian Grains Industry, supportedby Dr Vivi Arief from the University of Queensland.

"We are developing an automated pipeline to analyse the Australian CAIGE field trials for both a single-year analysis and a more-reliable three-year analysis," Dr Arief says. "We are also designing the field trials.

"The analysed results are provided to all collaborators and they can interrogate the data using an interactive R shiny app – a web-based app. The pipeline and the app can be applied to other similar projects."

Over the past 10 years, 5747 bread wheat, 2631 durum wheat and 2057 barley materials have been imported and subsets tested around Australia in 196 different trials.

Figure 1: Map indicating CAIGE field trials for bread (38), durum wheat (13) and barley (15) over the three-year period 2021–23. There were 1815 ICARDA and CIMMYT lines tested.



Source: CAIGE

OUTPUTS FOR GROWERS

The private sector breeding partners each year select promising lines from CIMMYT and/or ICARDA to use in their breeding programs. Many Australian varieties have been released with either CIMMYT or ICARDA lineage over the years.

In addition, straight variety releases from CIMMYT have already occurred, including the bread wheats Borlaug 100$^{\phi}$, Rebel Rat and Rebel 65$^{\phi}$ (all licensed to Rebel Seeds) and Jumbuck$^{\phi}$ (licensed to InterGrain). This highlights the importance of international collaborations in improving crop yields and disease resistance in the face of evolving production challenges. ☐

GRDC Codes UOS2203-004RTX, UOQ2301-010OPX

More information: Dr Julie M Nicol, julie.nicol@sydney.edu.au; Dr Vivi Arief, v.arief1@uq.edu.au

Enticing data scientists to take on grain challenges

Crowdsourcing data and analysis competitions is a way to connect specialists such as crop physiologists with computer and data scientists, bringing new skill sets to meet grain industry challenges

■ When Professor Scott Chapman begins a new academic year with crop physiology students, he always tells them they are privileged to have chosen a career in agricultural science.

"Agricultural science is one of the oldest science disciplines and we are tasked with applying the best new technologies to develop solutions to complex issues for growers," Professor Chapman says.

"However, only a limited number of students may choose this career path, especially as our society becomes increasingly urbanised and disconnected from the farmers who feed us. We need to innovate to cast our net wider."

That is exactly what an international team has done through a competition to entice data scientists into the agricultural space.

"Data competitions are a popular approach to crowdsource new data analysis methods for general and specialised data science problems," Professor Chapman says.

"Competitions appeal to scientists researching in this area and can really drive innovation as the results are recognised achievements."

The Global Wheat Challenge, managed by Dr Ian Stavness (University of Saskatchewan), was run in 2020 and 2021 to find more-robust solutions for wheat head detection using field images from different regions.

The Global Wheat Head Detection dataset used for the competition contained 6515 high-resolution RGB images representing 275,187 wheat heads from 16 institutions across five continents and 12 countries. A GRDC project directly supported labelling and competition activities in France (National Research Institute for Agriculture, Food and the Environment, INRAe and Arvalis) and Japan (the University of Tokyo).

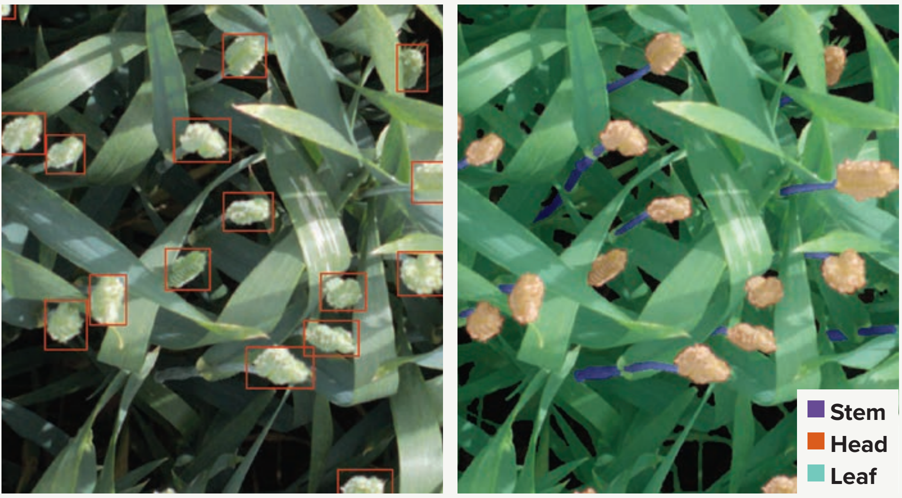


Photo: Andreas Hund, ETH Zurich

Feature extraction (left) from a plot of wheat followed by semantic segmentation where the pixels are classified into three groups: stem, head or leaf. These are two of the tasks in image segmentation and deep learning to train computers to understand visual information.

Broadly speaking, the aim was to create an algorithm to detect individual wheat heads in field images to estimate head density – which is one of the main yield components of wheat and which underpins our understanding of genetic and agronomic responses.

The first Global Wheat Competition attracted 2245 competitors and the second 432.

"We were involved and determined the winning challenge solutions in terms of their robustness when applied to new datasets," Professor Chapman says.

The competition was supported by a global consortium of research institutes including GRDC through two projects: UOQ2002-008RTX 'Machine learning applied to high-throughput feature extraction from imagery to map spatial variability' and UOQ2003-011RTX INVITA 'A technology and analytics platform for improving variety selection'.

NEXT ITERATION

Professor Chapman is the director of the University of Queensland node for the GRDC strategic partnership in Analytics for the Australian Grain Industry (AAGI), which is now collaborating with a larger global consortium to further automate the machine-learning-driven phenotyping of wheat.

"Semantic segmentation is a machine vision task that aims to classify each pixel as belonging to a type of object – for example, leaf, stem or head of a wheat plant," he says.

Semantic segmentation methods have revolutionised the development of agricultural automation. However, the availability of labelled samples limits the training and evaluation of new semantic segmentation deep learning methods.

"AAGI is supporting the labelling of more than 1000 new images from the consortium of universities (led by Dr Andreas Hund at ETH Zurich) to create a larger public resource for machine learning."

This AAGI project is contracting HiPhen, a company with expertise in high-throughput plant phenotyping, data acquisition and deep learning image analysis solutions applied to agriculture, to annotate the wheat image library.

"This will be a useful foundational resource to support future wheat research, trait identification, disease detection and much more." ☐

GRDC Codes UOQ2002-008RTX, UOQ2003-011RTX, UOQ2301-010OPX

More information: Professor Scott Chapman, scott.chapman@uq.edu.au;
Global Wheat dataset, global-wheat.com/gwfss.html;
doi.org/10.34133/plantphenomics.0059

Analytics internship brings a step change to field research

The productivity of research activity and the quality of outcomes have received a leg-up from a crop pathologist's internship with Analytics for the Australian Grains Industry

■ While laboratory and controlled-environment research equipped Dr Hari Dadu to be an experienced laboratory-based pathologist, he saw that more could be done if he could complement this with field-based research.

To make this a reality, Dr Dadu applied for an internship with GRDC-supported Analytics for the Australian Grains Industry (AAGI) to gain expertise in designing and analysing field trials, which are subject to greater spatial and temporal variation compared to controlled-environment studies.

The six-week research internship covered numerous analytically aligned topics such as data preparation, statistical modelling and building applications for broad dissemination of project results. Specific topics were:

- data diagnostics and preparation of data in a statistical software computing environment known as 'R';
- generating spatially optimal model-based designs for experimental controlled and field environment trials;
- introduction to computational statistical models to analyse complex agronomic data; and
- building and deploying new online applications that display and disseminate analysis results from the national disease management trials.

Research internship AAGI supervisors were Dr Beata Sznajder, Sam Rogers and Russell Edson, who are all based at the University of Adelaide's Biometry Hub led by Dr Olena Kravchuk and deputy Dr Julian Taylor.

Dr Dadu, a senior research scientist from Agriculture Victoria's Horsham SmartFarm, is a member of the field crops pathology team. His responsibilities include developing disease management strategies, conducting disease surveillance and screening germplasm for new fungal resistances for cereal crops.

He completed his PhD at the University of Melbourne in 2019 focusing on identifying and characterising resistance sources to Ascochyta blight within exotic lentil germplasm. To meet the demands of this role, which includes field-based research, Dr Dadu sought to upgrade his skills.

He says the first component of the internship involved analysis of historical data produced in the GRDC-supported national barley foliar pathogens project and investigation of the virulence of *Pyrenophora teres maculata* (the causal organism of spot form of net blotch disease, SFNB) within the Australian population.

"This was achieved using the statistical coding package 'R' and the linear mixed modelling package ASReml-R. The results showed variation in the virulence of SFNB populations and presented isolates of concern for the industry," Dr Dadu says.

He then developed a cloud-based Shiny app to assist Agriculture Victoria's disease surveillance activity.

"The aim of the app was to assist researchers to capture passport data of a disease sample during surveys and produce a quick summary through various data visualisation forms such as a map, table and graph for direct incorporation into project reports." Through the internship, Dr Dadu has developed an app named 'Victoria Disease Surveillance' and published it on a Shiny server for use during the season.

"The new statistical and computing skill set obtained through the internship has improved my ability to generate experimental designs, perform complex data analysis tasks using R and develop useful cloud-based applications for our team to use," he says.

"This has improved our research productivity as well as the quality of our research outcomes." Dr Dadu is now applying this new skill set to develop insights into the environmental effects of Septoria tritici blotch (STB) incidence in wheat, another GRDC research investment.

Dr Julian Taylor says that after Dr Dadu completed the internship, his analytical capabilities have grown significantly. For the STB work, Dr Dadu has generated most of the annual experimental field trial designs and undertaken the analysis of phenotypes.

"AAGI will continue to provide collaborative analytical support in 2024 for a more-complex integrated multi-environment analysis of STB phenotype and associated traits that are being collected by Dr Dadu and his team," Dr Taylor says. ☐

GRDC Codes DJP2104-004RTX, DJP2003-011RTX, UOA2301-005OPX

More information: Dr Hari Dadu, hari.dadu@agriculture.vic.gov.au

Photo: Luise Fanning, Agriculture Victoria

An internship at Australian Analytics for the Australian Grains Industry has built skills and confidence for Agriculture Victoria's Dr Hari Dadu to transition from controlled-environment pathology research to field-based research.

Phenomics – the link between crop genetics and performance

While crop scientists now have access to the genetic code of most crops, including wheat and barley, linking genetic information to field performance requires a crucial additional step – phenotyping, or plant phenomics

KEY POINTS

- Linking genetic information and field performance is a vital part of crop improvement
- Phenomics uses technology such as cameras, sensors, robotics and drones to accurately measure physiological traits and gene expression
- The Australian Plant Phenomics Network (APPN) comprises nine nodes across Australia to accelerate breeding outcomes for challenges such as drought, heat, frost and soil salinity
- APPN provides crop researchers and industry with access to advanced phenotyping infrastructure in controlled environments, at field sites and via mobile phenotyping units for deployment in remote areas


Photo: APPN

APPN CEO Richard Dickmann and GRDC Senior Manager – Enabling Technologies Tom Giles inspect APPN's latest high-spec GRYFN drone with RGB/Hyperspectral/LiDAR sensing payload.

Plant phenomics pairs sophisticated laser scanners, cameras, environmental sensors, robotics and drones with analysis of the collected data to measure traits such as nitrogen content, growth rate, leaf area, stress tolerance or shoot architecture.

This can be done in controlled environments to study specific traits in isolation, or in the field to test the real-world performance of new lines.

Traditionally, measuring phenotypic traits has been slow, labour-intensive and relatively subjective – especially when using visual scores to gauge disease resistance. Advanced imaging and analytics provide researchers with faster, more-objective results.

Critically, these digital systems gather multidimensional growth data non-destructively, so plant performance can be measured across the entire growth phase.

The Australian Plant Phenomics Network (APPN) provides a national plant phenotyping infrastructure supported by specialist expertise in botany, imaging systems, mechatronics, computer science and data analysis.

Supported by $60 million in core funding from the Australian Government's National Collaborative Research Infrastructure Strategy (NCRIS), plus co-contributions from partner institutions, state governments and GRDC, its mandate is to accelerate the development of climate-resilient crops for food and beverage production, plant-based pharmaceuticals and vaccines.

APPN operates growth rooms with precisely controlled light, temperature, humidity and irrigation conditions, greenhouses and field trial sites. Sensing technologies include RGB (red, green, blue), infrared and light detection and ranging (LiDAR) scanners that can create detailed images or 3D point clouds of individual plants.

Hyperspectral scanners are also used to identify indicators of plant stress invisible to the naked eye, while a range of environmental sensors record critical growing conditions.

Additionally, the Plant Accelerator®, APPN's node at the University of Adelaide, operates a fully automated X-ray computed tomography (CT) scanner, which can image plant structures and roots within soil columns. The technology has already been used for investigating stem structures to address barley head loss and cereal spike architecture in the quest for more frost-tolerant crops.

APPN chief executive officer Richard Dickmann says the organisation enjoys a productive relationship with GRDC spanning numerous research projects.

"Australia's grains industry is enormously important for the national economy and global food security, while our soils, environment and changing climate all present challenges that need to be understood and addressed as quickly as possible," he says.

"Plant phenomics accelerates the delivery of more-resilient, higher-yielding crops and more-sustainable farming practices."

Recognising these benefits, GRDC has made several direct investments in APPN infrastructure over the years, including co-supporting installation of the X-ray CT system and upgrades to biosecurity glasshouses.

GRDC is also supporting the purchase

of six mobile phenotyping units as part of this expansion. Enabling phenotyping in remote locations, each unit will carry matching LiDAR, RGB and hyperspectral systems and data will be collected via uniform pathways so they can be compiled into national data assets.

GRDC senior manager of enabling technologies Tom Giles says APPN's data-gathering capabilities will be complemented by the interpretive capabilities of GRDC's Analytics for Australian Grains Initiative (AAGI).

"APPN infrastructure can generate high-resolution data from the field, while the AAGI group will provide analytics support for researchers who need it," he says.

"GRDC sees phenomics and analytics as the key to saving crop research time and money.

"It means grains field researchers can accurately characterise key traits and gain greater insights to support crop genetic improvement and agronomic RD&E."

GRDC Code UOA2311-007FAX

Contribution from David Foxx, Ag Communicators

Infrastructure map

MAP KEY
Plant phenotyping capabilities

- **National suite of controlled environment facilities**
- **Network of nationally coordinated field sites**
- **Mobile phenotyping units to serve rural areas and field trials**

Proudly supported by

NCRIS
National Research Infrastructure for Australia
An Australian Government Initiative

APPN plant phenotyping infrastructure and expertise is strategically located at nine locations across Australia

A The University of Adelaide
B Australian National University
C Charles Sturt University
D Department of Primary Industries and Regional Development, Government of Western Australia
E La Trobe University
F The University of Queensland Australia
G The University of Sydney
H The University of Western Australia
I Western Sydney University

Source: plantphenomics.org.au

Enhancing crop trial data to strengthen variety decisions

Leveraging an international initiative, Innovations in Plant Variety Testing in Australia (INVITA) is aiming to bring a step change to grower insights from National Variety Trials and other grains RD&E field trials

Applications of remote-sensing and imaging technology to grains RD&E field trials are being developed through INVITA using GRDC's National Variety Trials network.

Photo: Dan Smith, University of Queensland

By Dr Javier Fernandez
The University of Queensland
Professor Scott Chapman
Queensland Alliance for Agriculture and Food Innovation, The University of Queensland

KEY POINTS

- **GRDC's NVT program is working with INVITA to provide improved, credible, faster crop variety data for growers, to help smarter variety selections for their own paddocks**
- **INVITA utilises advanced technologies such as imaging and drone data to improve variety selection, accounting for environmental effects**

Advances being made in plant variety testing in Europe are being used to strengthen and enhance Australian growers' insights from GRDC's National Variety Trials (NVT) program – the largest independent, coordinated grain crop evaluation trial network in the world.

NVT's purpose is to generate credible information for growers and agronomists to help with variety choice.

GRDC invested in the Innovations in Plant Variety Testing in Australia (INVITA) project in 2020.

INVITA leverages advances being made within the Horizon 2020 European initiative INVITE – Innovations in Plant Variety Testing in Europe.

In Australia, INVITA is developing a platform for improving variety selection by accessing and developing enabling technologies and analytics solutions that will be deployed within NVT to support more-profitable selection decisions by Australian growers.

Heading INVITA at the University of Queensland is Professor Scott Chapman, who has long-standing ties with a key INVITE partner, Wageningen University in the Netherlands, a top-ranked university for agricultural research. CSIRO Agriculture and Food is the other major collaborator.

The two main goals for NVT through INVITA are to improve:

- the prediction of performance at single sites, augmented by the use of imaging on the ground and by drone, and using this data to account for spatial field variability; and
- the ability to account for variation in crop performance in relation to environmental effects.

Ultimately, the research seeks to understand what is the right variety for the wide mix of environmental conditions experienced across the Australian grains industry.

It has the potential to improve growers' decision-making when it comes to selecting an appropriate variety for a particular environment and production system. Preliminary estimates indicate that INVITA methods that account for environmental information can improve variety yield predictions for specific seasonal conditions; for example, average conditions versus severe water stress.

EFFICIENT MONITORING OF TRIALS

INVITA monitors selected NVT sites intensively, integrating a diverse array of data sources including imagery, sensor data and manual observations to ensure comprehensive understanding of trial outcomes.

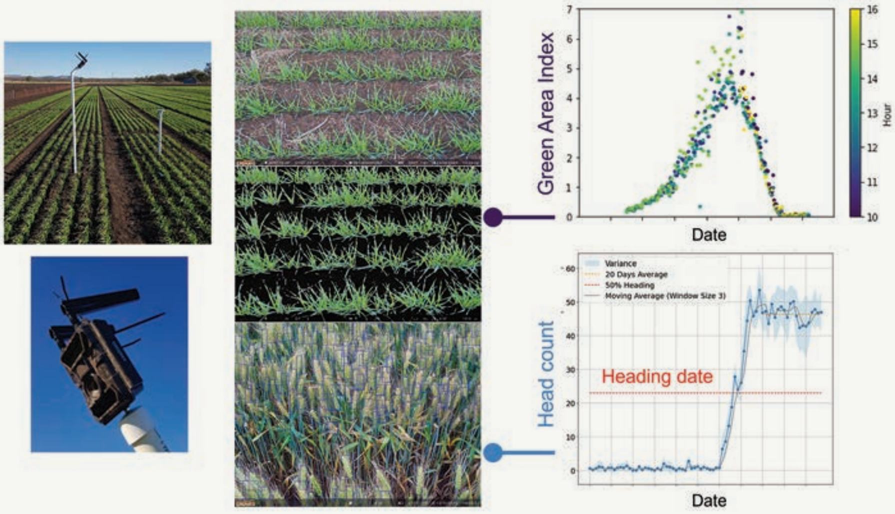
In field trials, the team utilises several methods for image collection at plot level, including static field cameras positioned at a 45-degree angle, handheld cameras or smartphones capturing images for each plot, and drone flights.

Describing in detail the sources of variability in these trials is crucial. These methods can capture variability in both spatial and temporal dimensions.

For monitoring temporal variations throughout the season, static field cameras are set up to capture images several times a day on a reference plot (Figure 1). INVITA uses advanced image processing techniques to infer plot-level crop status. For example, it allows for precise determination of the

Figure 1: Cameras are installed in the field to collect imagery data that can be analysed remotely for monitoring daily evolution of crop growth and heading dates using machine-learning detection algorithms.

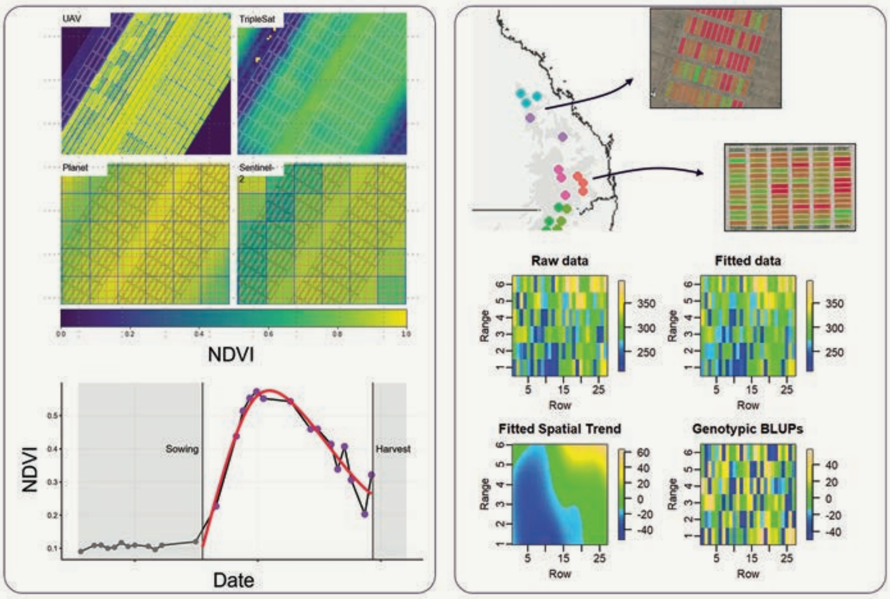
Real-time monitoring with field camera automation



Source: Javier Fernandez, University of Queensland

Figure 2: Satellite and unmanned aerial vehicle imagery are used to measure the temporal and spatial variability in trials. In this way, INVITA aims to account for additional sources of variability in NVT, such as weather or soil, to generate better variety yield estimates.

Multi-scale NVT measurements and simulation



Source: Javier Fernandez, University of Queensland

green vegetation cover throughout the season, representing a measure of wheat development for referencing satellite imagery. INVITA then analyses this data to understand the factors driving yield and other primary traits of interest.

This system can also support operations planning across the NVT network by providing real-time plot-level crop status to NVT staff and trial service providers.

By leveraging machine-learning algorithms, daily imagery data can also provide valuable insights into the timing and extent of heading (cereals) or flowering (pulses and so on) across trials.

Wheat crops are sensitive to stress occurring around heading stage, so having a precise determination of this stage provides critical information to identify environmental impacts that explain trial performance. This technology is being tested by INVITA and adapted to different environments and wheat varieties evaluated in NVT.

To analyse spatial variability, drone flights are used several times in the season. These drones are equipped with standard red, green and blue (RGB) cameras or with multispectral cameras that include near infrared (NIR) and near red-edge (NRE) wavelengths to match the spectral bands of satellite imaging.

The drone data is processed to generate detailed field maps at less than one-centimetre resolution. INVITA leverages the multi-scale integration of satellite imagery with drone and observational data to capitalise on the multispectral features and broad spatio-temporal coverage offered by satellites (Figure 2).

LEARNING FROM THE PAST TO UNDERSTAND THE FUTURE

Since the project began, INVITA has developed methods to retrieve historical imagery of past NVT sites through a combination of geometry and machine-learning algorithms. Temporal indices are computed at each pixel of the images to investigate drivers of crop performance in previous seasons.

The information collected by INVITA can add another layer of understanding to NVT of how each variety responds to the environment.

INVITA also coordinates a range of efforts to measure and describe local soil and climatic conditions associated with the location of the trial and the consistency of that location across different years.

By coupling this data with physiological knowledge, researchers hope to develop indices or stress scores that provide a better representation of genotype-by-environment interactions across the NVT.

The methods developed through INVITA will improve insights from NVT and other grains RD&E field trials, providing growers with the environmental context and enabling better decision-making. There is also potential for developing automated, data-driven, on-farm decision-making tools based on these processes for remote observation and inference of crop status. ☐

GRDC Code UOQ2003-011RTX

More information: Javier Fernandez, j.fernandez@uq.edu.au

Phenomics to improve disease management and resistance breeding

Phenomics is set to transform crop disease and resistance screening by providing high-throughput, accurate tools and techniques that reduce costs


Photo: GRDC

Blackleg of canola is one of several diseases being targeted by GRDC for improved screening methods using phenomic tools.

KEY POINTS

- Phenomic sensor technologies are evolving rapidly and are now being deployed in disease assessment
- Barley net blotches, wheat rusts and blackleg of canola are the three initial diseases being targeted for phenomic assessment by GRDC
- The tools will have application in pre-breeding, the GRDC-supported National Variety Trials and breeding programs

■ Plant pathogens reduce crop yields across the world. Two main strategies are used to combat this: breeding for disease-resistant plants and fungicide application.

Both approaches depend on identifying and measuring disease signs and symptoms. Today, non-invasive sensor technology, part of the domain of plant phenomics, is crucial for this, allowing high-throughput and repeated measurements on living plants.

While phenomic technologies have been used successfully to measure abiotic stresses such as response to water deficit, methods for biotic stresses such as plant diseases are less advanced. The interaction between plants and pathogens causes a variety of signs and symptoms; however, phenomic sensor technologies are rapidly evolving. The toolkit includes drone and platform-mounted sensors such as RGB, multispectral, hyperspectral, fluorescence and thermal sensors.

GRDC is investing in evaluating and improving these sensor technologies for rapid phenotyping of crop diseases and the following are four examples.

IN-FIELD HIGH-THROUGHPUT PHENOTYPING OF NET BLOTCH IN BARLEY

The most damaging pathogens to barley production in Australia are the net blotches: net form (NFNB) and spot form (SFNB).

Efforts to improve genetic resistance or develop fungicide controls for net blotches are critical to a productive future for Australian barley growers. However, progress in pre-breeding and breeding programs designed to improve net blotch resistance is limited by the lack of a method to accurately phenotype the disease in field trials. Visual scoring can be subjective, time-consuming and relies on expert pathologists.

A GRDC investment assembled a Net Blotch consortium with five programs spanning crop protection, genetics and enabling technologies.

Program 4 of the Consortium will deliver a new method for field phenotyping of net blotch in barley that is high-throughput, accurate and low-cost. This program is being led by Associate Professor Bettina Berger, the scientific director of the Plant Accelerator®, Australian Plant Phenomics Network®, at the University of Adelaide.

The aim of Program 4, which started in late 2023, is to deploy field phenotyping to increase the pre-breeding and breeding communities' capacity for evaluating net blotch resistance. The methods are designed for field-based phenotyping of the net blotches, with data acquisition protocols that can be implemented by pre-breeders and breeders.

Both ground-based imaging and drone-based imaging are being evaluated for the most robust and practical approach. These are suitable for phenotyping net blotch symptoms across key developmental stages (for example, tillering, stem elongation and heading) to enable genetic studies of net blotch resistance.

The methods are environmentally robust, enabling trials to be designed to establish the interaction between genetics and environment (GxE) in net blotch resistance.

They can also be broadly deployed across relevant investments in crop protection, genetic technologies, GRDC-supported National Variety Trials (NVT) and breeding efforts. These methods are specific to detecting net blotch, rather than broadly measuring plant stress symptoms.

GRDC Code UOA2306-002RTX
More information: Professor Bettina Berger, bettina.berger@adelaide.edu.au

MICRO-PHENOMICS: DIGITAL PHENOTYPING FOR ENHANCED DISEASE RESISTANCE

Program 3 of the Net Blotch Consortium investment, led Dr Peter Dracatos at La Trobe University, is developing both a macro and a micro-phenomic analysis to determine the mode of action of specific resistance genes either in isolation or in combination. These methods are being developed to generate laboratory-based insights into diseases. The overarching aim is to broaden the capabilities of the platform to phenotype both necrotrophic and biotrophic cereal pathosystems at seedling and adult plant stages. The team is focusing on both net blotches as its first pathogen subjects.

This work involves the development of a digital phenotyping platform based on a prototype pioneered at the Leibniz Institute of Plant Genetics and Crop Plant Research (IPK) in Germany. The platform comprises two components that perform micro-phenomic and macro-phenomic quantification of net blotch responses on barley.

The macro-phenomic component is a customised RGB camera with a robotic crane providing high-throughput capacity while facilitating accurate quantitative disease ratings. These are based on image analysis software optimised for specific pathogen interactions.

The micro-phenotypic component of the platform uses a Zeiss Axioscan sliding microscope to track the fungus in the plant tissue at early time points when symptoms are not visible to the naked eye.

The group at La Trobe University is collaborating with Analytics for the Australian Grains Industry (AAGI) and IPK to develop image analysis software based on machine learning and AI.

These partnerships will lead to extracting the most meaningful data to enhance current genomic approaches to identify new resistances and understand more about available net blotch resistance sources. Learn more at youtu.be/8Xp0f2B7mRM.

GRDC Code ULA2307-001RTX
More information: Dr Peter Dracatos, p.dracatos@latrobe.edu.au

OPTIMISING GENETIC CONTROL OF WHEAT RUSTS THROUGH IMPROVED PHENOTYPING

Annual savings from the control of stem, leaf and stripe rust diseases of wheat have been estimated at about $1.5 billion – about $1 billion of which comes from genetic resistance achieved through national rust pathogen monitoring and related RD&E.

Crucial to the development of profitable wheat varieties with adequate resistance is greenhouse and field screening of breeding populations so that lines with acceptable levels of rust resistance can be identified and progressed through the breeding pipeline.

This process is complicated by the three wheat rust diseases having different resistance mechanisms, different rust pathogen epidemiologies, and rust pathogen variability – and these change over time due to the emergence of new pathotypes.

Led by Professor Robert Park and coordinated by Dr Karanjeet Sandhu, the GRDC-invested Australian cereal rust control program (ACRCP) Phase 5 project will improve screening methodologies to quickly, accurately and cost-effectively identify susceptibility to current and emerging rust pathotypes in wheat germplasm. So far, the research team has optimised conditions for both plant growth and development of the three rusts. The program will also explore the potential for image and sensor-based phenotyping to measure the impact of rust symptoms in wheat under controlled conditions and in field. This is enabling fast-tracked studies of the expression of the two important types of resistance, all stage resistance (ASR) and adult plant resistance (APR), for all three rusts.

The APR screening cycle can now be completed in 35 days and multi-pathotype testing for APR is possible throughout the year, which is difficult under field conditions.

These accelerated and cost-effective methodologies developed for the screening of APR and ASR will help in the speed-breeding of wheat cultivars.

GRDC Code UOS2301-004RTX
More information: Dr Karanjeet Sandhu, karanjeet.sandhu@sydney.edu.au

PHENOMICS TO ASSIST BLACKLEG MANAGEMENT

Blackleg crown canker disease, caused by the fungal pathogen *Leptosphaeria maculans*, is responsible for major canola losses. Blackleg disease can be effectively and efficiently managed by using cultivars with host genetic resistance.

However, with major genes susceptible to breakdown, there is an ongoing need to ensure that new resistant varieties are available. Quantitative resistance (QR) is an important and durable component of host genetic resistance. However, like net blotch, breeding programs are limited by a method to objectively, quickly and accurately phenotype the disease in field trials.

A GRDC-invested project being led by Dr Luke Barrett at CSIRO, which began in late 2023, is developing tools to improve throughput and accuracy and also reduce the cost involved in field phenotyping QR to blackleg in canola. Specifically, the project is developing methods to:

1. automatically quantify crown canker severity from image data;
2. detect blackleg infection in field trials using drones; and
3. understand whether resistance to crown canker can be quantified in the field using non-invasive techniques (such as hyperspectral sensors).

The phenotyping tools described above will be developed with the level of throughput and accuracy required to enable improved efficiency in both the pre-breeding (for example, crop protection, genetic technologies, NVT) and breeding industries. ☐

GRDC Code CSP2307-006RTX
More information: Dr Luke Barrett, luke.barrett@csiro.au

Push to step up trait knowledge adoption

Despite substantial investments by agencies such as GRDC, integrating physiological traits into plant breeding for rainfed conditions remains challenging, prompting the exploration of cost-efficient methods such as phenomics to facilitate breeding

Photo: Connor Cassidy, CSIRO

Uploading a flight plan of the research station into the Hyspex Mjolnir – a hyperspectral imaging UAV drone capable of capturing wavelengths of light known to be associated with variation for physiological traits.

By Dr Anton Wasson
CSIRO
Dr Nicolas Taylor
The University of Western Australia

KEY POINTS

- **Physiological traits have proved challenging to integrate into breeding problems due to their complexity and cost of measurement**
- **A proof-of-concept project has been supported by GRDC with AGT to explore new ways of measuring physiological traits using phenomic tools**
- **Three physiological traits, identified by physiological scientists, are being assessed with new phenomic tools**

A major push is underway to make new knowledge on the physiology of wheat – and how trait variation affects growth – more accessible for commercial breeders.

Around the globe, agencies such as GRDC and their science partners have put substantial effort and investment into understanding the physiology of wheat and how trait variation affects growth, yet there are still gaps in the knowledge and tools required to deploy physiological traits in a breeding program.

This is because measuring many physiological traits can be complicated, expensive and highly technical. Also, in many cases the link between these traits and improved yield has not yet been demonstrated. Demonstration of this link can be particularly difficult if the trait is only relevant in a particular season or only measurable indirectly with yield.

Further, it is difficult to justify overhauling a breeding program to incorporate a new trait with already required traits where there is uncertainty about value and the expense of measuring this is high. Hence, the challenge is to demonstrate the value of a wheat trait and to make measuring the trait cost-efficient, to facilitate uptake.

The need is to develop methods that allow breeders to rapidly screen variation in novel traits in ways that are cheaper and easier than previously possible. This is where phenomics could play a significant role in next-generation measurement techniques that can be deployed to facilitate breeding.

ACCELERATED INTEGRATION OF PHYSIOLOGY-BASED WHEAT TRAITS

In 2021, GRDC invested in a five-year project with Australian Grain Technologies (AGT) to accelerate the adoption of physiology-based traits in wheat. This is being done through R&D partnerships between academic researchers and commercial wheat breeders.

The aim is to deliver wheat varieties to Australian growers with significantly enhanced yield potential under limited water conditions, given the challenges of consistent and profitable production in rainfed environments.

In Phase 1 of the project, researchers and breeders identified three questions that would need to be answered 'yes' for any physiological traits to be included in the project:

1. Does the trait have a clear value proposition for growers?
2. Can the trait be accurately and cost-efficiently measured across environments?
3. Does variation for the trait already exist within Australia's commercial breeding germplasm or will it need to be introduced?

The project surveyed 25 Australian and international plant physiologists across nine institutions to identify relevant physiological traits for Australian environments. The survey identified 27 above-ground plant physiological traits. Each trait was assessed with a Decision Tree for Physiological Traits, developed by AGT.

A trait's path through the Decision Tree identified challenges for validation of each trait(s) in the context of a commercial breeding program and these were carefully documented. No traits fully satisfied all requirements for validation in a commercial setting due to uncertainties in the adoptability of the methods, the genetics and/or the value proposition.

However, three traits were considered "most promising to validate". These were:

- rate and duration of grain filling;
- respiratory traits; and
- photosynthetic capacity and efficiency.

There was evidence that all three traits might be predicted with hyperspectral measurements of the plants from the visible to the infrared.

VALIDATION OF TRAITS

Phase 2 of the project engaged three 'trait teams' drawn from project partners with expertise in the development and measurement of these traits from the Australian National University (ANU), University of Western Australia (UWA) and CSIRO.

Wheats that represented the extremes of genetic diversity for the identified traits were brought together with elite germplasm suited to the Australian wheatbelt.

Recognising the promise of the hyperspectral measurements, a fourth team was assembled to attempt to measure them from a drone – an unmanned aerial vehicle (UAV).

This collection of 96 lines was grown at three field sites within the AGT trial network in 2023.

Genetic diversity for the traits was identified in the elite material. Airborne hyperspectral imaging of the crops was found to be a possibility for a commercial setting. However, new predictive models for the traits would need to be built and tested.

BUILDING ON INVESTMENT

Early in 2024, GRDC invested in an add-on project – AcceleTraitPlus. This project, led by CSIRO, will use the AGT field trials combined with the expertise and ground-based measurements of UWA, plus results from the main project, to develop high-throughput, spectral-based UAV methods for these traits.

The project will develop predictive models for the physiological traits for use with UAV hyperspectral imagery.

The aim is to develop methods that are accurate, scalable and cost-effective. UWA's Nic Taylor says the project is about taking research that has been developed in the laboratory and tested in research plots, and then providing a pathway to deploy it in a breeding program.

In 2024, validation work is underway at CSIRO's purpose-built, state-of-the-art, 290-hectare research facility, Boorowa Agricultural Research Station. This facility is equipped with a full array of sensors that will provide further valuable insights.

CSIRO has invested in a $450,000 HySpex Mjolnir, a high-quality hyperspectral drone from Finland. This complements its existing fleet of cameras and will provide data directly for the purpose of building the models. This drone will be flown more frequently at the Boorowa and the New South Wales AGT sites to add additional data to the data collected during the 2023 field season.

Machine learning and artificial intelligence techniques will be used to build the predictive models for the traits. The models themselves will also be investigated to identify key spectral features for the development of adoptable and scalable imaging solutions as the cost of hyperspectral technology drops. □

GRDC Codes AGT2108-001RTX, CSP2401-016RTX

More information: Dr Anton Wasson, 02 6246 24739, anton.wasson@csiro.au

The need is to develop methods that allow breeders to rapidly screen variation in novel traits in ways that are cheaper and easier than previously possible. This is where phenomics could play a significant role in next-generation measurement techniques that can be deployed to facilitate breeding.


Dr Dongxue Zhao and QAAFI's 'Root mobile', which produces 3D root activity maps, in the field at a farm on the Darling Downs, Queensland.

Photo: Professor Daniel Rodriguez

Novel techniques identify drought-tolerant roots

New developments in phenomic tools are shedding light on the finer dynamic interactions of crop roots and yield that could boost productivity and drought tolerance

By Professor Daniel Rodriguez

Queensland Alliance for Agriculture and Food Innovation, the University of Queensland

Given that grain production in Australia is mainly limited by water availability, it is rather perplexing how little is known about the rooting system – the most critical plant organ to access soil water and nutrients.

The architecture, anatomy and function of the root system offer untapped opportunities for crop improvement and productivity gains in the grains industry.

However, root traits are hard to measure and the lack of quick, cheap, accurate and functional root phenotyping approaches in the field has limited the capacity of breeding, agronomy and precision agriculture to develop valuable traits and products.

We do know that the crop's genetic background and the environment (soil, climate, management) interact to alter the architecture of the rooting system, or root phenotype. However, rarely have studies on root architecture been able to relate these differences into valuable information such as differences in root function – and therefore implications for yield, or yield stability in the field.

Lack of success is due to the complexity and limited understanding of the relationship between root form, root function and grain yield. A major bottleneck has been the fact that characterisation of the below-ground parts of crops is laborious, expensive and subject to large errors, as usually only a limited part of the rooting system can be sampled.

Root studies are usually done by growing single plants in pots, root chambers or tubes, or destructively extracting soil samples containing roots from the field. Another problem has been that research appears stubbornly focused on trying to visualise root architecture, ignoring the rather weak and highly variable relationship between root form and root function.

Also, the predominant focus of these approaches has been limited to just measuring the mean value of a trait – for example, rooting depth. This overlooks the fact that the root system is highly responsive to the environment, and that different genotypes show different capacity to adapt to their environment when under stress.

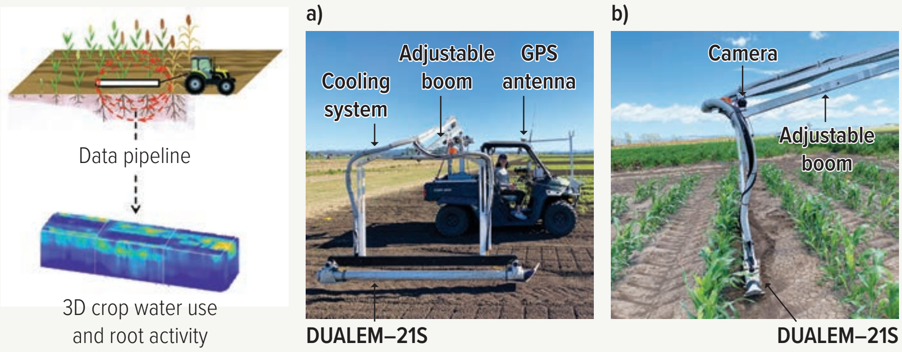
Aiming to alleviate this bottleneck, a GRDC-invested project being led by the University of Queensland's Queensland Alliance for Agriculture and Food Innovation (QAAFI) is delivering root phenotyping tools to enable valuable crop root structure and function traits to be measured non-destructively with at least 15 per cent greater accuracy, cost-effectiveness, or throughput than current methods.

The project brings together a multidisciplinary team of national and international researchers from QAAFI[1], the University of Queensland, the Western Australian Department of Primary Industries and Regional Development[2] (DPIRD), CSIRO[3] and the Leibniz Institute of Plant Genetics and Crop Plant Research[4] (IPK) in Germany, to work in collaboration with seed companies (Pioneer Seeds Australia, Pacific Seeds, Australian Grain Technologies and LongReach Plant Breeders) and providers of digital and precision agriculture services (Airborn

Insight and DataFarming) to deliver actionable solutions to industry and growers.

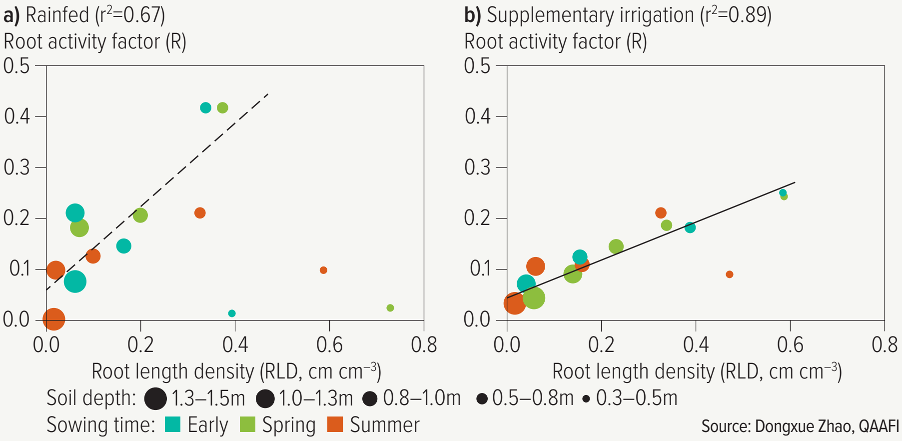
The project will also build capability for the Australian industry through the training of postgraduate and postdoctoral scientists in the use of these new approaches for examining functional crop rooting traits across highly contrasting environments.

Figure 1: QAAFI's high-throughput functional phenotyping of rooting systems being applied at a sorghum trial.



Source: Dongxue Zhao, University of Queensland

Figure 2: Relationship between the EMI-derived root activity factor (R: y axis) and root length density (RLD: x axis) in the soil profile, for the sorghum variety MR Buster grown under rainfed, supplementary irrigation, and three times of sowing: early, spring and summer at Nangwee, Queensland. The size of the dots represents the soil layer.



Source: Dongxue Zhao, QAAFI

NOVEL APPROACH

The project's approach is integrating new, functional, high-throughput phenotyping tools with the trait pipeline approach applied in pre-breeding programs and commercial seed companies, where there is simultaneous development of screening methods and evaluation of valuable traits in relevant germplasm. Applications for agronomy and precision agriculture will be also explored.

In our approach, we combine time-lapsed electromagnetic induction (EMI) surveys, drone imagery, crop ecophysiology principles and machine-learning techniques to build 2D and 3D representations of root growth and activity in the soil profile.

The methods were developed within the GRDC project 'Optimising sorghum agronomy in the northern grains region' and applied to map plant-available water capacity in growers' paddocks in another GRDC-invested project. In principle, an EMI unit is dragged over the soil in between rows (Figure 1) to derive 3D maps of crop water use in the soil profile that, together with the use of drone imagery and APSIM modelling, are used to calculate an index of 'root activity' for each soil layer, down to the maximum rooting depth.

We have shown that this index of root activity was highly related to important root traits such as the extent of root length density in the soil profile – obtained by soil coring – across a wide range of environmental conditions (Figure 2). Importantly, our results also show that differences in root traits between commercial sorghum hybrids were associated with differences in yield and yield stability

Our approach to high-throughput functional root phenotyping in the field is quick, cheap and accurate, and when applied across contrasting growing environments not only allows researchers to assess the average value of a root trait but also its variability (in other words, plasticity) in response to changes in environmental conditions or management practices such as plant density, row configuration, fertilisation, soil amelioration or irrigation.

This is the first time that a root phenotyping approach in the field has allowed us to explain changes in crop yield, yield components and their stability, offering an opportunity to overcome the present root phenotyping bottleneck in cereals for breeding and agronomy.

Validation of these new sensing techniques, and collaboration with root anatomy experts from IPK in Germany, will open opportunities to examine further below-ground crop root traits of interest to boost crop performance, such as maximum rooting depth, the rate of root advancing front, shallow to deep water use, root hydraulic conductivity and root anatomy traits.

DEPLOYMENT

The project team is working closely with wheat and sorghum pre-breeding programs and breeding companies, as well as providers of digital agriculture services, providing a clear pathway to market. This ensures that project outputs will be relevant, valuable and actionable by/to industry, and adoption accelerated. ☐

GRDC Code UOQ2312-009RTX

More information: Professor Daniel Rodriguez, d.rodriguez@uq.edu.au; doi.org/10.1016/j.compag.2022.107409; doi.org/10.21203/rs.3.rs-4120028/v1; agrogeo24.curve.space/articles/AG0016

[1]Dr Dongxue Zhao, Associate Professor Karine Chenu, Professor Lee Hickey, Professor David Jordan, Professor Emma Mace, Associate Professor Andries Potgieter, Dr Vijaya Singh. [2]Dr Hammad Khan. [3]Dr Anton Wasson. [4]Professor Hannah Schneider.

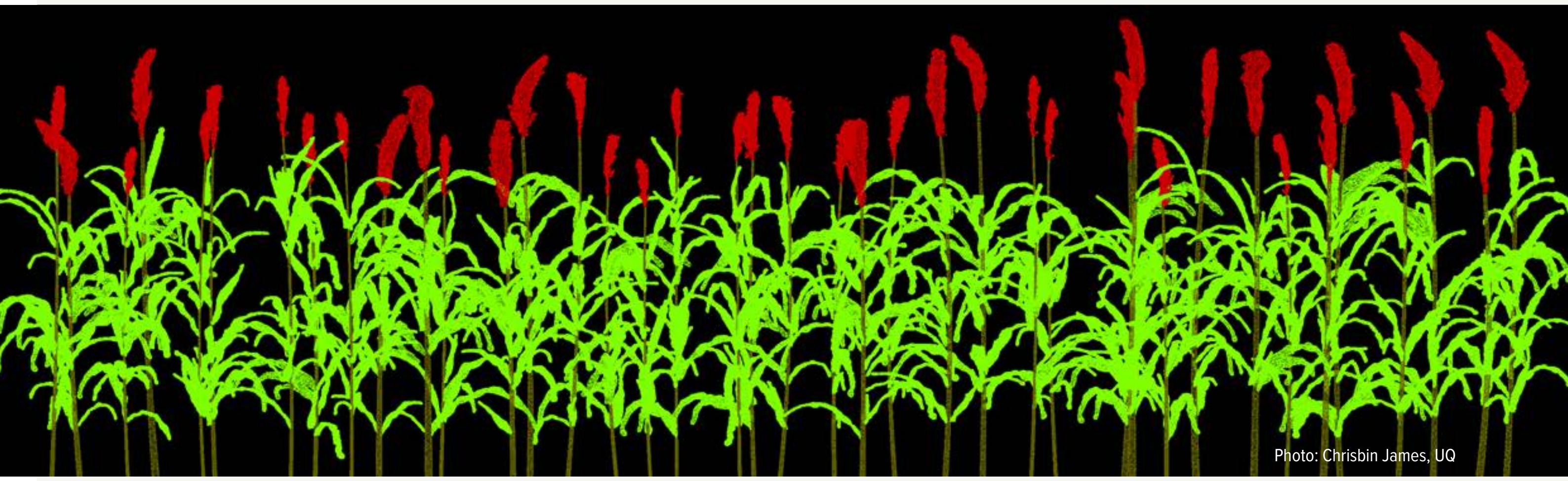


Photo: Chrisbin James, UQ

An artificially generated sorghum canopy used to train machine-learning models so that they can extract information from imagery captured by cameras on UAVs in sorghum trials and fields. The different colours are heads, stems and leaves, which the machine learning model is trained to identify.

Grains research recruits from a wide science nursery

Continually evolving production challenges in the grains industry are attracting more students from diverse backgrounds to apply data, analytics and AI to solve them

■ The Australian grains industry needs highly capable people to provide insights and decision support to every facet of grain production. To ensure this, GRDC invests significantly in Capacity & Ability, an enabling program that is part of a suite of enablers in the Research, Development & Extension Plan 2023–28.

The objective is to access the best people and technologies from across the globe, including from other industries such as space, mining and medicine. Further to this, GRDC also aims to foster an environment that supports diversity and innovation, connecting people and providing time and space to be creative.

A key vehicle for GRDC's Capacity & Ability activities is GRDC Research Scholarships. These support PhD candidates to deliver research that addresses or builds opportunities for Australian growers. The three-year top-up scholarships, worth $35,000 a year, provide high-achieving students with financial and industry support to complete their PhD in an area aligned with GRDC's RD&E Plan.

The following snapshots showcase the work of three GRDC Research Scholars whose studies align with big data and phenomics investments.

Daniel Smith, University of Queensland
Principal supervisor: Professor Scott Chapman
Thesis: Improving variety prediction using environment information

After switching from an undergraduate photography degree to agricultural science at the University of Queensland in 2014, Daniel Smith undertook several undergraduate research scholarships where he found that photography could be used to solve complex scientific problems.

Completing his undergraduate studies in 2018, Daniel began a PhD study in 2020 at the University of Queensland under Professor Scott Chapman at the School of Agriculture and Food Sustainability.

Daniel is exploring UAV-based high-throughput phenotyping (HTP) approaches for the prediction of wheat biomass across multiple environment types and at multiple growth stages across crop development.

Unmanned aerial vehicles (UAVs) are increasingly used by plant breeders to improve speed and accuracy of measuring plant traits in field plots and are significantly reducing the cost of field data collection. The use of UAVs has been validated for measuring time of flowering and crop canopy height.

With other sets of measurements, it is possible to estimate more-complex traits – for example, radiation use efficiency (RUE).

Visual red, green and blue (RGB), thermal and multispectral cameras mounted on UAVs are now common tools for monitoring crops, with light detection and ranging (LiDAR) and hyperspectral tools also coming online as they are miniaturised.

As part of his study, Daniel investigated RUE measurement through direct changes in crop biomass and the fraction of photosynthetic active radiation that is absorbed (FiPar) in the crop canopy. To do this, he used high-resolution multispectral and RGB cameras.

RUE is closely linked to photosynthesis efficiency and has been identified as having potential for improving grain yield. By developing ways to estimate RUE using UAVs, Daniel's research may add extra value to breeding programs by enabling the incorporation of physiologically relevant traits into the selection process.

As the heritability of these traits in crops is high, the UAV-assisted measurement method Daniel has validated

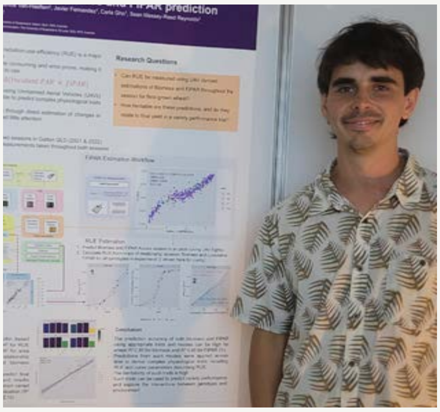


Photo: Shanice Van Haefton

Daniel Smith


Photo: courtesy Chrisbin James

Chrisbin James


Photo: Dr Anirudh Belwalkar, University of Melbourne

Andrew Longmire

would help breeders predict variety performance and explore the interactions between genotypes and environment.

Chrisbin James, University of Queensland
Principal supervisor: Professor Scott Chapman
Thesis: Virtual agricultural imaging and sensing through artificial intelligence and computer vision

Chrisbin James is a data scientist and joined Professor Chapman's team in 2020. He has an undergraduate degree in information technology from Indraprastha University in Delhi, India, and a master's degree in data science from the University of Queensland.

Chrisbin is applying computer vision and machine learning to phenotyping challenges in the grains industry. He is developing methods for evaluating panicle-related traits such as grain count and panicle weight for sorghum. Panicle-related traits have been traditionally measured using destructive, slow and expensive methods. He is focusing primarily on panicle grain number – a trait that is highly correlated with grain yield and also an important criterion for selecting heat-stress tolerant varieties.

In the first year of his PhD project, Chrisbin developed a deep-learning algorithm that uses a combination of images and surface-level 3D models of sorghum panicles to estimate grain count on panicles collected from breeding trials.

This year, he is focusing on scaling his methodologies to identify the panicle morphology based on canopy architecture measured non-destructively in the field.

He is using UAV-based 3D reconstruction techniques, which use low-altitude flights and NeRF (neural radiance fields) deep-learning models for creating high-resolution 3D canopy models. Initial results show the quality and shape of individual panicles derived from UAV-based 3D reconstruction correlates well with the laboratory measured panicle shape.

Training deep-learning models to identify panicle shapes requires large amounts of labelled 3D datasets. Chrisbin is also developing a 3D sorghum canopy generation framework based on high-resolution panicle models he is collecting to simulate sorghum canopies for generating data to develop deep-learning-based phenotyping models for LiDAR and UAV 3D data (see image on page 20).

Andrew Longmire, University of Melbourne
Principal supervisor: Professor Deli Chen
Thesis: Wheat grain protein content assessment via plant traits retrieved from airborne hyperspectral and satellite remote-sensing imagery

After completing a biology degree at Monash University and a master's in agricultural science at the University of Melbourne, Andrew Longmire completed his PhD in 2023, also at the University of Melbourne.

His studies were supervised by Professor Deli Chen from the School of Agriculture, Food and Ecosystem Sciences (SAFES) and Professor Pablo Zarco-Tejada, Faculty of Engineering and Information Technology and SAFES.

Professor Chen and Professor Zarco-Tejada are experts in soil nitrogen dynamics and remote sensing of vegetation. Andrew undertook his PhD as a mature-aged student. He brought several years of experience to the task, having worked in project management, consulting, as a national park ranger, and in bulk food logistics. His PhD was informed by his deep understanding of plant physiology, agronomy, resource management in cropping, and on-farm data sources, acquired through academic study, extensive work experience and a lifelong passion for productive landscapes.

The overarching objective of his project was to combine remote-sensing image collection and processing with machine learning to enable accurate, reliable and spatially explicit predictions of grain protein content in durum and bread wheat.

Aware of the large amount of fertiliser applied to Australia's grain crops – and the importance of grain protein to the dietary and economic value of wheat – Andrew wanted his research to offer real benefits to growers' bottom lines and to the environment.

Through combining remote sensing with data collected on farms, his results offer potential for precision agriculture, for strategic harvest planning and/or fertiliser application planning.

Andrew took a multidisciplinary approach, combining state-of-the-art science techniques from airborne and satellite remote sensing, model inversion and statistics with data collected by header-mounted grain protein content monitors. These can potentially be applied to problems of global importance and real-world relevance to grain growers. ☐

GRDC Codes UOQ2004-013RSX, UOQ2306-005RSX, UOM1903-001RSX

More information: Daniel Smith, daniel.smith3@uq.edu.au; Chrisbin James, chris.james@uq.edu.au; Andrew Longmire, longmirea@student.unimelb.edu.au

Assessing sensors for enhanced canola plant architecture selection

New technology is being explored for its application in determining yield components for canola to accelerate yield gains

By Eva Hufnagel
Fraunhofer-Institut für Integrierte Schaltungen
Dr Bas van Eerdtl
Phenokey

KEY POINTS

- **Selecting for improved canola varieties via yield components has proved challenging using conventional means**
- **Next-gen phenomics using a variety of sensors is being evaluated as a solution to this bottleneck**

■ Yield potential in water-limited environments depends on crop transpiration, transpiration efficiency and harvest index. Canola has a lower harvest index compared with cereal crops, which is especially pronounced in water-limited conditions.

Improving yield components in canola has been challenging due to difficulties in selecting promising genetic material using standard techniques.

Next-generation phenomic technologies could help overcome these challenges by developing high-throughput methods for selecting traits that optimise harvest index and yield in canola.

One method is to estimate biomass in the paddock non-destructively using combined sensor data. To this end, GRDC is supporting a pilot study with a Dutch company, PhenoKey, which designs and implements tailored automation solutions. The pilot study is being conducted in collaboration with Fraunhofer Institute for Integrated Circuits – Embedded Systems and Real-Time Computing, a division of the Fraunhofer Institute IIS, which specialises in the development and application of innovative X-ray and computed tomography (CT) technologies. In this instance, PhenoKey and Fraunhofer are undertaking a feasibility study using a phenotyping platform to collect data from an X-ray system, light detection and ranging (LiDAR) and GPS sensor.

The goal is to assess the biomass of yield components on a paddock scale for different canola varieties using this technology and compare the sensor-derived data with the actual measured biomass.

If the correlation between the two biomass values is robust, this project would be the basis of developing a rapid phenotyping method to assess harvest index in canola. Such a high-throughput method of phenotyping would provide a useful tool to accelerate the breeding of higher-yielding canola varieties.

METHODS

The phenotyping platform used in this study is a remotely controlled field vehicle equipped with three different sensors. The sensors are an X-ray source with an X-ray detector, a LiDAR sensor and an RTK-GPS sensor (Figure 1).

The X-ray sensor measures the absorbance of the plants between the source and detector in 2D projections as the vehicle is driving through the paddock. The amount of absorbed X-ray intensity for plant material is highly correlated with the physical density of the plants.

The measured density values are used to estimate the virtual biomass, which later will be correlated with the actual biomass. As the vehicle does not have constant velocity, due for instance to ground conditions, the RTK-GPS data is used to stretch or compress the 2D X-ray images.

Furthermore, the GPS data is used to link the X-ray data to the different plots to obtain a biomass value per plot, which can later be compared with the actual measured biomass after harvesting. The LiDAR sensor generates a point cloud of the plot in a 3D-coordinate system. This data is used to estimate the total volume of each plot from the soil to the top. The volume is used to extrapolate the value of the estimated biomass derived from the X-ray data, since the X-ray sensor cannot scan the full volume of the plot.

INITIAL FINDINGS AND NEXT STEPS

The results from studies in 2023 showed that the sensor-derived data is suitable for the non-destructive estimation of virtual total biomass per plot in a canola paddock.

In 2024, a more in-depth appraisal of canola biomass production will be undertaken in this feasibility study. Using 36 plots containing six varieties, four scanning campaigns are planned: before flowering, after flowering, at the beginning of pod formation and shortly before harvest.

This will enhance the dataset and strengthen the assessment of this phenotyping method, validating its correlation with actual measured biomass in canola, a step forward in creating high-throughput, breeding program-friendly methods for selecting traits that optimise harvest index and yield in canola. □

Photo: Fraunhofer IIS

Figure 1: Phenotyping platform with different sensors: X-ray system, LiDAR and RTK-GPS sensor for use in canola.

GRDC Code PHE2210-001RTX

More information: Bas van Eerdt, b.vaneerdt@phenokey.com; Eva Hufnagel, eva.hufnagel@iis.fraunhofer.de

GRDC invests in data cataloguing to transform R&D

GRDC has invested significantly in research, but finding and accessing the data from these investments has been challenging, prompting the development of a data catalogue to improve accessibility and useability

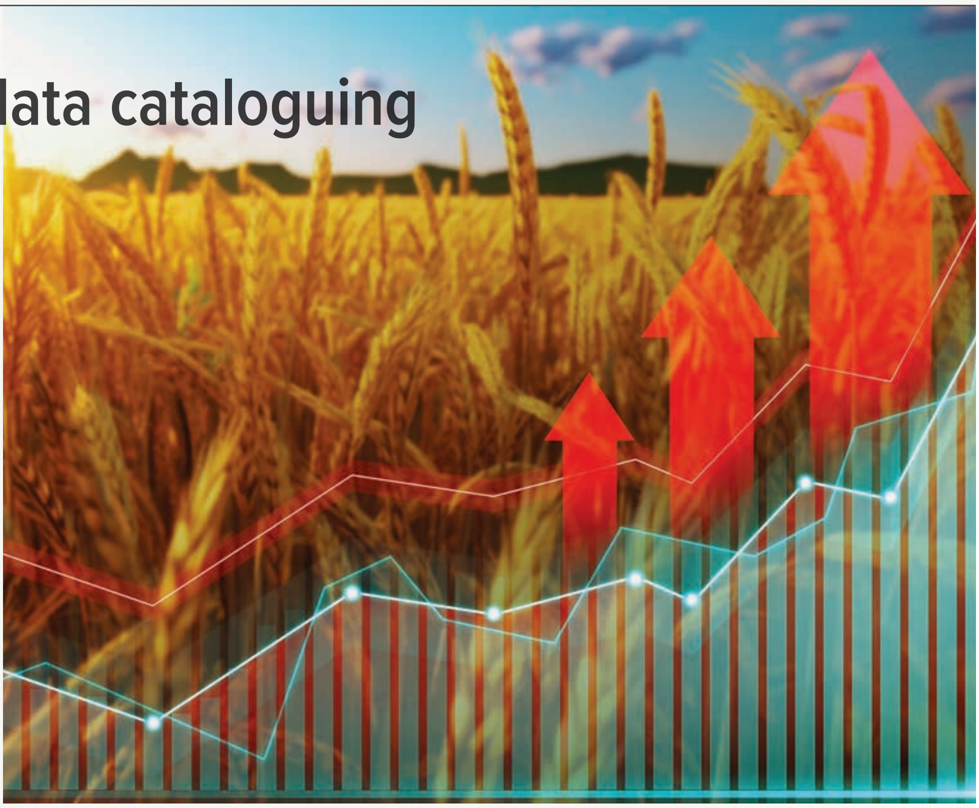


Photo: 123RF

A goldmine of data from more than 30 years of investing in research and development will be curated and catalogued through a GRDC investment with Aristotle Metadata.

■ GRDC has spent $3.6 billion on research, development and extension (RD&E) for the benefit of Australian growers over the initial 30 years of its operation. Although data is now recognised as an asset, the data that was generated through the investments is hard to manage and could be easily lost.

Historically, libraries served as information hubs. With computers and the internet, digital cataloguing emerged, enabling online access to resources. Library catalogues list available books, while data catalogues list datasets and databases. Library catalogues guide users to shelves, while data catalogues direct to data repositories. Library catalogues indicate book availability, similar to data catalogues indicating data access. Both provide details such as author, publisher and creation data.

In an endeavour to collate and archive research data, GRDC made an initial investment in the Data Partnership Initiative, which brought together 12 Australian research institutions in collaboration to make GRDC-supported research data available under the internationally recognised FAIR principles, which state that data should be findable, accessible, interoperable and reuseable.

To build on this work, in 2022 GRDC invested with Aristotle Metadata via Elysium Digital Pty Ltd to build a data catalogue.

Aristotle Metadata chief executive Samuel Spencer uses cropping analogies when describing what the investment will achieve for GRDC, as he says farming is under-recognised as a data-driven industry.

"We are now in the information economy, where data is a key asset like a grower's farm," Mr Spencer says. "A data inventory is like a garden on your farm; you don't just plant it and walk away, it requires continuous maintenance to increase its use."

Like library catalogues, data catalogues are not new. There are well-established catalogues in Australia and overseas. Examples include the Australian Research Data Common's Research Data Australia, a research data catalogue that is national infrastructure and has an Australia-wide scope, while CSIRO's Data Access Portal lists the datasets found in its data repository.

The data catalogue will allow its target audience of researchers, GRDC investment managers, companies and others to find the research data generated from previous and future investments. Researchers and GRDC investment managers will be able to know the extent of Australian grains RD&E data on a topic with a simple search.

The catalogue will unlock new opportunities to drive innovation by bringing together comprehensive and diverse datasets that can then have more-powerful analytics (for example, meta-analysis, machine learning and artificial intelligence) applied to them to derive innovative insights that were previously unattainable.

The resources will be able to direct RD&E focus as the existing datasets will help researchers and investment managers understand the state of the art in grains-related RD&E and so enable them to direct their efforts towards valuable and new frontiers. Greater value will be extracted by re-using datasets in new projects; the value and return on investment from previous GRDC investment will be amplified.

Mr Spencer says by searching for datasets in the catalogue, users will be able to identify data relevant to their R&D activities, separating the wheat from the chaff.

"Ultimately, the data catalogue will reduce the cost of research and accelerate research outcomes, avoid duplication and reduce errors."

Establishment of the GRDC data catalogue will also support compliance and governance responsibilities and help GRDC to meet its obligations under Australian Government data policy to publicly disclose its data assets where legal and commercial considerations allow. ☐

GRDC Code ELY2202-001SAX

More information: Sam Spencer, sam@aristotlemetadata.com

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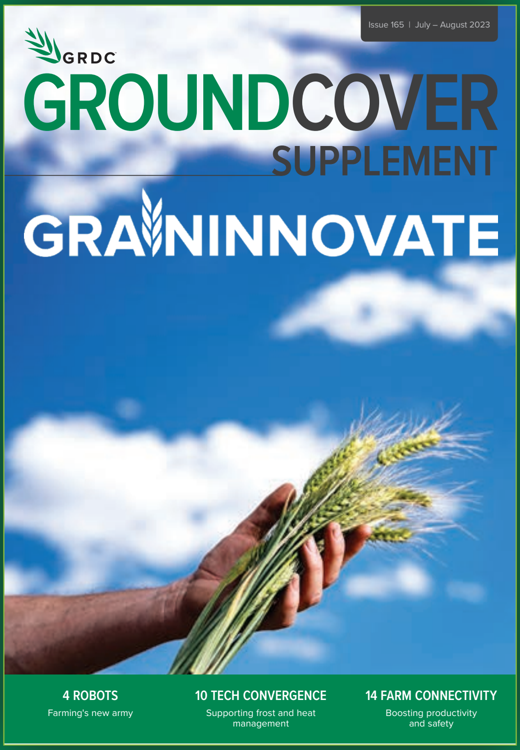

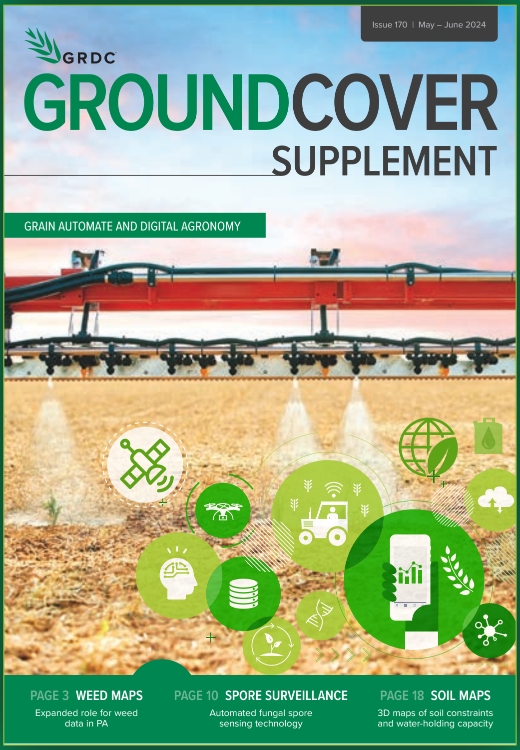

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