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Why phenomics?

The triple threat of a global food security crisis, climate change and bourgeoning demand for biofuels means that scientists are under increasing pressure to provide rapid, cost-efficient solutions to feed hungry, growing populations and advance emerging biofuel industries. To solve these global issues, all of the strengths and disciplines of plant biology need to be integrated to develop high-yielding crops adapted to changing environments. Such integration is the province of the Australian Plant Phenomics Facility.

Phenomics, a relatively new scientific term, describes the study of how the genetic makeup of an organism determines its appearance, function and performance. Phenomics is a cross-disciplinary approach to studying the connection from cell to leaf to whole plant and from crop to canopy.

The Australian Plant Phenomics Facility will provide the knowledge base and facilities for the comprehensive and continuous analysis of plant growth and performance using cutting-edge technologies. It is a national facility open to all researchers and the first publicly funded facility of its kind anywhere in the world.

Using new technologies, the APPF is capable of taking non-destructive and destructive measurements on parts of the plant above and below ground over the course of the plant's lifecycle. By linking these phenomic measurements – such as leaf size, temperature, colour, or plant growth over time – new plant varieties can be selected and engineered using the genetic diversity in cultivated and wild plants.

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IN BRIEF

Twice the rice for the same price

As part of an international research consortium aiming to address the global food security crisis, CSIRO scientists will be developing genetically modified rice plants in the newly established High Resolution Plant Phenomics Centre.

The consortium, coordinated by the International Rice Research Institute and funded by the Bill and Melinda Gates foundation, seeks to alter the photosynthetic mechanisms of rice to increase yield and reduce water and fertiliser use. [cont. page 2]

Some cool plants don't mind salt

The CSIRO salinity research team will be using the new High Resolution Plant Phenomics Centre and it's specialised 'Phenomobile' vehicle to take sophisticated measurements of wheat and barley plants grown in saline conditions in the lab and in the field. [cont. page 3]

An echidna in the hand is worth two in the bush

CSIRO scientists have developed an instrument that is revolutionising the way forest and vegetation structure is measured, producing valuable information for commercial forestry, environmental assessments and plant phenomic research. [cont. page 2]

Remote tools for crop research

CSIRO scientists are developing a reliable high-throughput phenotyping approach to detect drought-adaptive traits in wheat crops.

Understanding how specific genetic characteristics help crops produce more grain when water is limited requires observation of complex traits through different stages of plant development and under different drought conditions. [cont. page 3]

The Plant Accelerator, Adelaide

With over 1km of conveyor systems and state-of-the art imaging, robotic and computing equipment the Plant Accelerator, based at the Waite Campus of the University of Adelaide, will be a world-leading plant growth and analysis facility.

The high technology glasshouse facility will accommodate 160,000 plants a year in programs aimed at improving economically important crops such as wheat, barley and grapevines.

Physical attributes (phenotype) of plants will be automatically, continuously and non-destructively measured at the Facility over time, recording morphometric data such as shoot mass, leaf number, shape, angle, and leaf colour and senescence using visible spectrum images; leaf water and carbohydrate content using near infrared images; leaf temperature using far infrared images; removal of water from soil in pots using near-infrared wavelengths; plant health by monitoring the state of chlorophyll using fluorescence imaging; and, measuring gene expression using fluorescent proteins.

The Plant Accelerator will serve as the national headquarters of the Australian Plant Phenomics Facility's two nodes.

The High Resolution Plant Phenomics Centre, Canberra

High Resolution Plant Phenomics Centre, Canberra

Measuring plant growth and development using the most recent advances in robotics, imaging and computing, the Canberra node of the facility – High Resolution Plant Phenomics Centre (HRPPC) – will put Australia at the forefront of global plant phenomics.

Next generation research tools will be developed and applied to probe plant function and performance. Research undertaken at the Centre located at CSIRO, Black Mountain and The Australian National University in Canberra, will lead to the development of new and improved crops, healthier food, more sustainable agricultural practices and will maintain and regenerate biodiversity.

The HRPPC, launched in August 2008 and up-and-running next month, will examine food and fuel crops from the single plant to the ecosystem level. Researchers using the HRPPC will explore metabolism and physiological processes within plants ('deep phenotyping') and dissect traits to discover their mechanistic basis ('reverse phenomics').

Two levels of service will be provided by the HRPPC. First, projects can be housed in the 'research hotel' environment where screening systems can be developed to answer a researcher's specific questions using facility staff and resources and then deployed in the Centre and in the user's home institution.

Second, users material can be screened for specific attributes using one or more of the modules housed at CSIRO or the ANU. This node of the facility will focus on flexibility from cereals to dicots and woody perennials at all stages of development.

The High Resolution Plant Phenomics Centre will serve as the sister facility to the Plant Accelerator based at the Waite Campus of the University of Adelaide. Together the Canberra and Adelaide nodes will comprise the Australian Plant Phenomics Facility.

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Australian Plant Phenomics Facility
The High Resolution Plant Phenomics Centre

The Australian Plant Phenomics Facility is an initiative of the Australian Government conducted as part of the National Collaborative Research Infrastructure Strategy (NCRIS) and is supported by the South Australian and ACT governments. The project is a collaboration between CSIRO, the University of Adelaide, The Australian National University and industry groups. The total investment in the Facility across Adelaide and Canberra is $40 million.

Further information:
www.plantphenomics.org.au

Twice the rice for the same price

[cont. from page 1]

Most cereal crops, such as rice and wheat, convert solar energy into carbohydrates using a photosynthetic process called C_3. Crops like maize and sugarcane use a more advanced type of photosynthesis, known as C_4. This mechanism, discovered by CSIRO scientist Hal Hatch in the 1960s and '70s, allows C_4 plants to produce carbohydrates more than twice as efficiently as rice or wheat, using less water and about half as much nitrogen.

Developing a type of rice able to produce more grain with less resources will be a huge step towards solving the global food security crisis.

This crisis is the result of a burgeoning world population, a decline in arable land area and water for agriculture due to urbanisation, competition for agricultural land from biofuels and feedstocks, as well as increasing fuel and fertiliser costs. Recently, global cereal reserves fell to levels representing less than 30 days of consumption and rice prices rose almost 400 per cent compared to 5 years ago.

The stagnation of annual gains in yield from cereal breeding programs is a major factor in the current food crisis. Cereal yields are becoming limited by the capacity for the plant to fix sufficient carbon during its lifecycle and translate this carbon into harvestable grain. C_4 rice could significantly improve the situation.

C_4 plants combine a more efficient photosynthetic mechanism with a cellular structure which enables them to accumulate carbon more readily. Several genes will need to be introduced into rice to make it C_4-like. This is a challenging, long-term project expected to take about 10 years.

Dr Bob Furbank, CSIRO, Dr Susanne von Caemmerer, ANU, and their international collaborators will use the new facilities of the High Resolution Plant Phenomics Centre to more quickly screen rice varieties and select those that already possess some C_4-like traits. These will then be modified by introducing more C_4 genes, and screened again to assess how the new genes affect photosynthesis, growth and yield.

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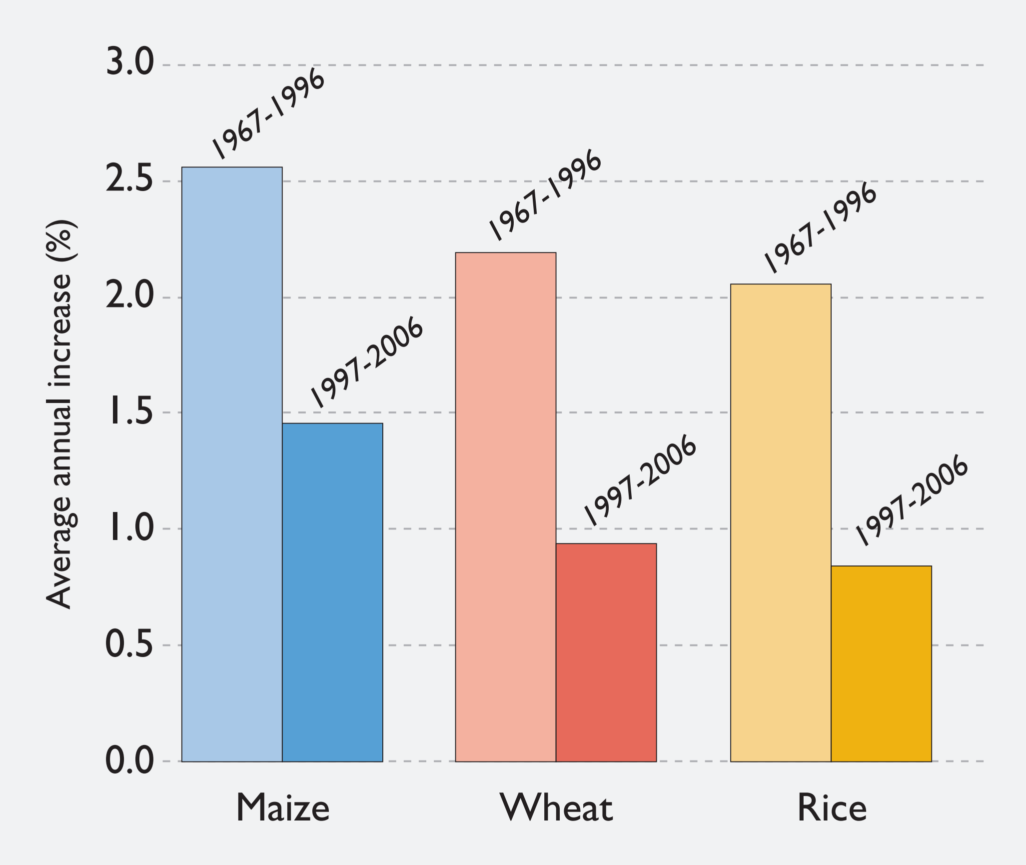

The quantity of grain produced on each hectare of land is still growing, but not fast enough to keep pace with demand. Source: New Scientist, June 2008

An echidna in the hand is worth two in the bush

[cont. from page 1]

In 2001 CSIRO began the development of a ground-based light detection and ranging (LiDAR) instrument known as ECHIDNA®. This remote sensing technology is spiky, just like its namesake, but in this case the spikes are needles of light shot in all directions to directly measure the structure and geometry of the forest.

ECHIDNA® employs the principle of laser range finding by measuring the time lapse between transmitted and reflected laser pulses. A unique aspect of ECHIDNA® is the acquisition of full 'waveforms' rather than discrete range measurements. Waveforms capture the intensity of energy reflected from all objects intercepted by the laser beam. Waveform data are useful for separating woody and non-woody plant material and can also produce point cloud datasets suitable for detailed structural characterisation of individual trees.

Simple 2D projection of ECHIDNA Validation Instrument (EVI) cumulative waveform intensity mature *Pinus radiata*

ECHIDNA® has been tested in a range of forest sites and the results have been compared to measurements recorded using traditional techniques. "ECHIDNA has shown to be an efficient and powerful instrument for the complex process of assessing the three-dimensional structure of a forest, which can be very laborious and time consuming work using manual techniques", says Dr Darius Culvenor, CSIRO.

Combined with above-canopy sensors, ECHIDNA® is currently being used to estimate forest biomass to assist research into the carbon cycle in world forests. The instrument is also being used to monitor changes in canopy leaf area as part of catchment-scale studies into forest water use.

The CSIRO team is looking at some new exciting developments which include producing a smaller version of ECHIDNA® and implementing research programs to assess crop biomass, biodiversity and fire hazards.

This research has been supported by Forest and Wood Products Australia (FWPA).

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Scanalyzer saves time and money in cowpea trials

While field trials are essential to develop new crop varieties, they can also be expensive and time-consuming. Using world-first technology to image plant growth in the greenhouse with the LemnaTech GmbH Scanalyzer at the Australian Plant Phenomics Facility, scientists can quickly select the best lines for field trials and thus reduce the number of lines that need to be field tested.

Dr TJ Higgins, Deputy Chief of CSIRO Plant Industry, will be one of the scientists using the Canberra node of the APPF facilities to screen hundreds of cowpea lines prior to starting field trials. The Scanalyzer takes three images of a plant at regular intervals and combines them to produce a 3D reconstruction measuring size and shape, a good measure of growth rate. Not only does it have the power to scan hundreds of lines over several weeks, but will also measure growth without destroying the plants.

Dr Higgins and his team have been working with the Rockefeller Foundation, the United States Agency for International Development and African Agricultural Technology Foundation to develop cowpea varieties with built-in resistance to a major caterpillar pest. Cowpeas are a protein-rich legume relied on by over 200 million people in sub-Saharan Africa. They are highly adapted to the drought conditions and poor soils of the region, but are not resistant to the legume pod borer, which can sometimes wipe out up to 80 per cent of a crop in a single year.

Over the past several years, Dr Higgins and the CSIRO team have succeeded in genetically modifying cowpeas to include a Bt insect resistance gene to protect against pod-borers. The next hurdle they face is finding a line to use as a parent for the breeding programs in Africa that not only resists the pest but produces new varieties suited to different agricultural zones. The time taken to identify the best line will be greatly reduced by using the Scanalyzer at the APPF.

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Remote tools for crop research

[cont. from page 1]

This research relies heavily on the study of crops in the field to give a better appreciation of the value of drought-adaptive traits in a real-world setting.

Phenomics field studies usually involve highly laborious, expensive and time-consuming measurements. In addition, using manual techniques where each variable is measured separately does not allow for season-long monitoring of complex traits such as the dynamics of crop water use.

Dr Fernanda Dreccer, Dr Tony Condon and their team are tackling this problem by integrating several remote sensing technologies, such as spectral reflectance and canopy temperature, to simultaneously evaluate multiple traits, quickly and cheaply.

Remote sensing technologies are non-invasive and produce 'snapshot' measurements that are highly dependent on the field context at that particular time. For example, depending on the intensity, timing and evolution of a drought event relative to crop development and size, a 'hot' canopy could indicate a poor rooting system or an efficient canopy response to conserve water by reducing transpiration.

To overcome the static nature of single observations, remotely sensed information will be integrated with other crop, weather and soil data with the aim of producing season-long phenotypic information. This will provide new insights into the interaction between the genotype and the environment that will help to accelerate the detection of wheat genotypes better suited to cope with drought.

This type of work requires a multi-disciplinary approach, and the CSIRO team has highly valuable collaborators nationally, such as the Australian Plant Phenomics Facility (APPF). Overseas the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Centre for Maize and Wheat Improvement (CIMMYT), currently working on a portfolio of projects aiming to develop drought tolerant wheat crops.

This research has been funded by CSIRO, the Grain Research and Development Corporation (GRDC), the Generation Challenge Programme and the Australian Centre for International Agricultural research (ACIAR).

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The 'phenomobile' was designed and developed by the HRPPC to integrate a range of remote sensing technologies for phenomics field studies

Some cool plants don't mind salt

[cont. from page 1]

The measurements will allow Dr Rana Munns, Dr Richard James and their team, to accurately screen the performance of a range of Australian and overseas cereal varieties growing in saline soil.

The best plants will then be used as parents in breeding programs, aiming to deliver new wheat and barley varieties with improved salt tolerance.

Thermographs of barley seedlings provide clues to osmotic stress tolerance

Salinity is a significant problem for farmers in many regions of Australia. Salt tolerant crops will provide more options for farmers who are managing this salt-affected land.

The study, funded by the Grains Research and Development Corporation, aims to identify wheat and barley varieties able to keep their stomata open even when salt stress is applied.

When a plant is grown in saline conditions, it finds it harder to draw water out of the soil. This results in the stomata closing to reduce transpiration, but closed stomata limit the plant's CO_2 intake, inhibiting photosynthesis and ultimately reducing yield.

Closed stomata and reduced transpiration also result in the leaves becoming warmer. For this reason, measuring canopy temperature with infrared thermography can be used as a quick and accurate way of determining the degree of stomatal opening.

In their research, Dr Munns and Dr James will be selecting varieties that maintain a lower leaf temperature when exposed to salt and will be assessing how this trait impacts on total plant biomass and grain yield.

Many wheat and barley varieties will first be assessed in the lab. The best varieties emerging from this initial screening will be planted in the field where the 'Phenomobile' will be used to move through the experimental plots and take a number of measurements, including canopy temperature and total biomass.

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VISITING INTERNATIONAL RESEARCHERS

Joe Berry, a consulting professor with the Department of Biological Sciences, Stanford University, USA, studies the physiological mechanisms of plants. Professor Berry will be speaking in the Ecosystem Dynamics and Climate Change session on Thursday afternoon about climate change and monitoring plant ecosystems.

Professor Peter Gregory, Director of the Scottish Crop Research Institute (SCRI) since 2005, is interested in root growth of crop plants and their interactions with soils. He also undertakes research on global environmental change and food security in collaboration with staff at the University of Dundee. "Staff at SCRI and the APPF are already working together on studies of barley genotypes and phenotypes and I hope that this conference will facilitate an increase in this activity". Dr Gregory will be speaking about CT scanning and development of roots in hostile soils during the Abiotic Stress session on Wednesday morning.

Dr Hamlyn Jones, Professor of Plant Ecology in the Plant Science Division, College of Life Sciences, University of Dundee, UK, is a plant ecophysiologist whose research aims to improve our understanding of the characters that enable plants to be adapted to specific environments and to tolerate environmental stress. "The APPF is an exciting initiative that brings together a wide range of technologies for identifying plants adapted to environmental stresses, and I am looking forward to working with the group to improve screening of breeding populations for drought tolerance which is probably the most important requirement for increased crop production in the future", he says. Dr Jones will be speaking in the Ecosystem Dynamics and Climate Change session on Thursday afternoon about IR imaging of plant canopies.

Dr David Kramer, Professor, Institute of Biological Chemistry, Washington State University, USA, is interested in "understanding how photosynthesis operates in the living plant, how it is co-regulated to provide the correct amount of energy in the correct forms without producing toxic side reactions, and how these processes enable or limit the productivity of plants". Their group hopes to apply the in vivo spectroscopic tools they are developing to large-scale phenomics efforts. Dr Kramer will be speaking in the Growth and Yield session on Thursday morning about non-invasive measurements of chloroplast function in leaves.

Dr Michael Purugganan, Professor of Biology with the Center for Genomics and Systems Biology, New York University, USA, is primarily interested in plant evolutionary genomics research. In particular, his research examines the evolutionary and ecological genomics of plant adaptations, the genetics of plant domestication and the nature of selection in plant genomes. "High-throughput phenotyping is still the major impediment in much of genomics research, and the Australian Plant Phenomics Facility promises to move the entire field forward," he says. "I am excited with the possibilities of working on joint projects between NYU and the Facility, including work on adaptation of plants to diverse environmental challenges". Dr Purugganan will be speaking in the Ecosystem Dynamics and Climate Change session on Thursday afternoon about understanding the limits of environmental plasticity.

VISITING INTERNATIONAL RESEARCHERS

Professor Julie Scholes, Professor of Plant and Microbial Sciences at the University of Sheffield, UK, has research interests in the areas of molecular plant-parasite interactions (parasitic plants and fungal pathogens) and the development of chlorophyll fluorescence imaging systems to quantitatively image photosynthesis with high spatial and temporal resolution. She says, "The APPF is an exciting facility that will aid the development of new crop varieties to enhance agricultural production in response to environmental change". Professor Scholes will be speaking in the Biotic Stress session on Wednesday afternoon about chlorophyll fluorescence imaging of fungal diseases of cereal crops.

The scientific interests of **Dr Uli Schurr**, Director of the Institute for Phytosphere Research (ICG-III) at Forschungszentrum Jülich, Germany since June 2001, primarily involve the diversity of plant adaptations to the dynamic environment, the dynamics of growth, transport and their interaction with the variable environment, and how plant structure and function provide the basis for natural and managed biosystems. He says, "Plant Phenotyping is the bottleneck for identifying and establishing novel traits that are essential for higher food and biomass production and for higher resource". Dr Schurr will be speaking in the Growth and Yield session on Thursday morning about generic approaches to plant phenotyping as exemplified in imaging roots and root function in soil.

Dr Achim Walter, Deputy Head of the Institute for Phytosphere Research (ICG-III) at the Forschungszentrum Jülich, Germany, and his team are investigating the basic mechanisms of growth control and the dynamic reactions of leaf and root growth to changes in ecofactors. "APPF facilitates an urgently needed link between basic research on development of model organisms and field experiments, thereby securing the future use of plants", he says. Dr Walter will be speaking in the Growth and Yield session on Thursday morning about digital imaging of growth dynamics.

Dr Terenzio Zenone is a post doctoral researcher at the University of Toledo Department of Environmental Sciences, Ohio, USA. Dr Zenone's research interests are related to in-field experimental activities: measuring water and carbon dioxide fluxes in terrestrial ecosystems, separating the contribution of autotrophic and heterotrophic soil respiration, quantifying above- and below-ground biomass, determining Net Ecosystem Production, calculating and modelling the full budget of greenhouse gases in forestry and agricultural ecosystems. Dr Zenone will be speaking in the Growth and Yield session on Thursday morning about ground-penetrating radar and measuring roots and water in soil.

Research papers from the 1st International Plant Phenomics Symposium will be published in a special issue of Functional Plant Biology in October 2009.

International collaboration

Dr Kerstin Nagel
Forschungszentrum Jülich, Germany

Low rainfall is a major constraint for Australian wheat growers and it is crucial that we understand how crops adapt to drought conditions and climate change. The CSIRO wheat research group is developing new wheats with greater shoot or root growth to cope with drier conditions.

Dr Kerstin Nagel, normally based at the Institute of Chemistry and Dynamics of the Geosphere (Phytosphere) at Forschungszentrum Jülich, Germany, was the first international scientist to visit the High Resolution Australian Plant Phenomics Facility in Canberra. Dr Nagel examined how the new wheats directed roots for greater water use efficiency and how shoot leaf area and light exposure relate to root growth.

Together with Drs Michelle Watt, Xavier Sirault and Bob Furbank, the world-leading technologies of the HRPPF were used to develop a system to measure shoots and roots simultaneously using non-invasive time-lapse photography.

Dr Nagel found that the new wheats partitioned carbon to roots or shoots depending on genotype. Wheats with greater leaf area recovered quicker to re-watering surface layers, and root growth was greater into dry deep soil when the leaves received higher light, independent of leaf area.

Using a simplified version of the time-lapse system will assist in future selection of traits for greater water use efficiency. Collaboration continues between CSIRO, the Forschungszentrum, Jülich and the Australian Plant Phenomics Facilities in Canberra.

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The CSIRO wheat team is developing new wheats with greater shoot or root growth to cope with drier conditions

Plant Phenomics: future-proofing world agriculture

The future of plant phenomics is largely determined by the four major challenges facing global agriculture: food security, water availability, appropriate biofuel feedstocks and climate change. The need for quantitative tools to rapidly select plants which will perform and yield better in our future climate is a major driver for new technologies.

Phenomics is more than a high throughput sieve to select better germplasm. The spectral imaging technologies employed in the Australian Plant Phenomics Facility (APPF) have the power to non-invasively drill down to biochemical composition and function, as well as to measure biomass, crop growth, water use and photosynthesis.

Methods to quantify plant performance at all scales, from the cell to the leaf, the canopy, plot, paddock or ecosystem level, will revolutionise plant breeding. Phenomics databases, linked to the burgeoning gene sequence information for crop species, will be crucial to utilisation of the outputs from the APPF and other facilities world wide. Together these tools will also allow farmers to monitor their agricultural performance, make informed decisions about choice of plant varieties and improve the precision to their agronomic practices.

An important role for these technologies in delineating next generation traits is 'reverse phenomics'. Take, for example, a genotype that appears drought tolerant. Understanding the basis for the trait, at the physiological and genetic level using high resolution phenomics tools, provides the knowledge base to find the next set of leads necessary to underpin progress in plant breeding.

The challenges facing agriculture are not going away. World economies will look to plant biologists and agricultural scientists to feed us and fuel us for many years to come. Rising to this challenge will require a rejuvenation of Plant Physiology research and integration of all the –omics disciplines - systems' biology in the broadest sense.

Dr Bob Furbank
Scientific Director and Team Leader,
High Resolution Plant Phenomics Centre

About CSIRO

CSIRO is Australia's national science agency. It is one of the largest and most diverse scientific research organisations in the world with over 6,500 staff located across 57 sites throughout Australia and overseas.

CSIRO's research effort spans agriculture, communications and IT, health, manufacturing and construction, minerals and energy, services, the environment and transport and infrastructure.

CSIRO Plant Industry is one of CSIRO's 17 divisions and is ranked internationally as a leading research centre for plant science.

It has around 720 staff at eight sites across Australia and conducts basic and applied research to promote profitable and sustainable agrifood, fibre and horticultural industries, develop new plant products and improve natural resource management.

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