Plant Sciences

AT THE AUSTRALIAN NATIONAL UNIVERSITY

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Plant Sciences Special

ScienceWise

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Cover Image: Meconopsis racemosa – the blue Tibetan poppy

Welcome to the Plant Sciences Special

Dr Tim Wetherell

Plants touch the lives of every single person on the planet. They provide all our food - even meat comes from animals raised on plants. They generate the free oxygen in the atmosphere that we all breathe and they act as one of the largest sinks for the atmospheric CO_2 that we're so fond of creating. A huge number of medicines are either directly extracted from plants or are derived from plant compounds and of course, plants look nice in our gardens. Given all this, it's not surprising that plants and their biology have been a focal point of science for hundreds of years.

However, plant biology in the twenty first century is very different from the taxonomy, illustration and classification that fascinated the Victorians. Modern plant scientists employ the latest technology and a battery of sophisticated instruments to really get to grips with every aspect of plants from the actions of individual genes within their cells to the behaviour of entire forest ecosystems.

One of the key changes in modern plant science is that researchers now understand the molecular and cellular processes that underlie the behaviour and diseases of plants and this enables them to tackle problems far more effectively. The importance of such a thorough knowledge of genetics, biochemistry and physiology cannot be overstated. This is the key to solving the practical problems of environment and nutrition that the world faces today.

Back in the mid nineteenth century a fungus, *Phytophthora infestans* created devastating damage to the potato harvest in Ireland and other areas of Europe leading to untold human death and misery. The fungus hasn't disappeared, but a better understanding of it's nature and modes of action mean that it's unlikely to ever have the same impact again. But the fungicides and land management policies used to counteract Phytophthora infestans only became possible once the nature of the organism involved was properly understood.

The threats we face in the modern world are different but no less real. Growing world population coupled with climate change will critically challenge our food supply in coming decades. These same pressures will influence the productivity and persistence of natural plant communities, with important follow on effects on climate itself. The only effective way to address these problems, is science. In this Plant Sciences Special, we are featuring just a few of the exciting research projects being undertaken at The Australian National University. These range from understanding the effects of changing climate on plants to developing new plants better able to cope with environmental stress and offering better crop yields.

If you like a challenge and care about our natural world, then why not consider coming to study plant sciences at ANU? It could be the first step on the road to one of the many interesting and important careers available to plant science graduates!

New Rural Assistance Scholarships Available!

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Why Tibetan Poppies Have the Blues

Studying the Impact of Humans on Meconopsis

PhD student Hongyan Xie is passionate about the flora, fauna and unique culture of her native Tibet. Her current research focuses on an exceptionally beautiful genus of poppy known as Meconopsis. Among these is the famous blue poppy, but different species grow a range of striking colours including yellow, red and purple. These poppies grow in the thin air of the alpine regions of Tibet and are amongst the highest growing flowering plants on Earth. However the fragile ecosystem that supports Meconopsis is under threat from three different directions.

Hongyan Xie on a field survey in Northern Sichuan, China

Climate change is beginning to increase temperatures in many alpine regions of the world. The stark reality of this was underlined by a recent decision by European banks not to offer development loans to lower altitude ski resorts in the Alps, for fear that there would be no more snow. In the case of Meconopsis, the problem is that with increasing temperatures, competitor species are able to colonise its habitat. The poppies can't easily move to higher altitudes because the soil, rainfall and other environmental factors are different. An area that has been too high to support plant life for hundreds of thousands of years has very much less organic matter in the soil than a vegetated area. In the course of evolution, plants can accommodate such factors but not on the short time scale of the current changes.

Meconopsis racemosa

The second threat to the poppies is their value in traditional Tibetan medicine. Meconopsis in combination with other local herbs is used to treat inflammation and to assist in the healing of fractures. In addition to local needs, traditional Tibetan medicine is becoming increasingly popular in China. This has raised the market price of the plants, which encourages locals to supplement their incomes by gathering poppies whilst out on the mountains tending their yaks. Unfortunately, Meconopsis is extremely difficult to cultivate and to date, efforts to grow them in commercial quantities have proved unsuccessful. As a result, all medicinal plants must come from specimens collected in the wild.

The third threat to Meconopsis comes from increasing human population, which in turn leads to more yaks and heavier grazing. Although yaks don't eat the poppies directly, they do displace smaller grazing animals into areas where the poppies grow. More humans also means more picking and more demand for medicine.

Establishing whether or not these three pressures on the poppies are causing their numbers to decline is a matter of careful survey work. But establishing the root cause of such declines is a lot more complicated. Hongyan came to Australia to learn more about plant biology and conservation; she found the expertise she needed at ANU and CSIRO Entomology.

Through the course of her studies, Hongyan hopes to fill in many of the sketchy details of the life cycle of various species of Meconopsis. Of special interest is the mechanism of pollination. The study region is a centre of diversity for bumble bees, which are well suited to higher altitude environments. In the short warm part of a summer day in the mountains bumble bees can be seen busily moving from flower to flower, their furry bodies coated with pollen. In the cool of the afternoon hoverflies settle down inside the poppy flowers where they shelter for the night. As they fly off in the warm of the following day they too can be pollinators. It seems that a large part of the reward for pollination in this case is the provision of shelter from the cold of the alpine night.

Ironically, one of the first major contributions to come from this study has been a discovery in entomology. During the course of collecting samples of pollinating insects, Hongyan found a previously unreported species of hoverfly. After consulting with experts at CSIRO and the Smithsonian Institute in the USA, the fly was declared a new species and as its finder, Hongyan was given the honour of naming it. Arctophila khamensis after the region of Tibet it inhabits.

Whilst the Meconopsis poppies are beautiful and economically important in themselves, their plight is linked to that of many other plants and animals in the area including the newly discovered Arctophila khamensis. Hongyan explains, "You can think of Meconopsis as an indicator species. It's charismatic and people care about it, but what happens to Meconopsis will also affect what happens to other species that may be less visible and less attractive, but are just as vital to the complex webs that form an ecosystem.

Arctophila khamensis sheltering in Meconopsis flower

Often called "the roof of the world" Tibet is famous for its spectacular natural beauty.

Drought Resistant Wheat

Helping to Protect Australia's Food Supply Against Climate Change

As climate change begins to tighten its grip on the world, many regions including Australia, are starting to experience increasingly erratic weather patterns. Most climate models predict that the vast wheat growing areas of Southern Australia will become significantly dryer over the next fifty years with serious economic implications. The 2002-03 drought resulted in a 20% reduction in agricultural income, which in turn resulted in 1.6% drop in GDP! Consequently anything that may help food crops like wheat survive dry periods has got to be a very good thing for Australia.

A group of plant scientists from Thailand, Argentina and Australia now at The Australian National University, have been studying a subtle mutation in Arabidopsis (a small, rapid growing plant) that may have important implications for drought resistance throughout the plant kingdom. The group is lead by Dr Gonzalo Estavillo and Professor Barry Pogson.

"This work actually began purely by chance when we were looking at different mutant varieties of Arabidopsis that had unusual responses to high light. We discovered a particular mutant, *sal1*, that survived longer than the normal plant under water deficit conditions, and seeing the obvious potential, we began to investigate." Dr Estavillo says.

The *sal1* mutant lacks just one protein, SAL1. Although the exact function of SAL1 is still debated, it's known to be important to the physiology and biochemistry of plants. The group have been studying where the protein is located in the cell, its role in intracellular signalling and in regulating the amount of water that travels through the plant. Their aim is to better understand the exact function of SAL1 and why its absence should improve a plants ability to withstand drought.

"We're really impressed by how many processes depend on SAL1. For example, the regulation of the amount of water in the plant is governed by SAL1. The pool of plant-made chemicals (or metabolites) is also greatly affected in the plants lacking the SAL1 protein and the functioning of many different genes is altered. Similarly, the amounts of several key regulatory players in signals that control plant development and responses to drought are different in the *sal1* mutant."

Because of its relatively well-understood genome and rapid growth, Arabidopsis is a "model" plant used by many biologists to study the interplay of genes with plant physiology. But in order to realise the great practical benefits of drought tolerance, the mutation must of course, occur in a food crop such as rice or wheat.

If additional new genes were required to achieve drought tolerance in a plant like wheat, then scientists might splice the new gene into the existing genome. But this would come with the burden of extensive safety testing and also incur public concern about GM food stock. However, because the basis of this particular mutation is a missing gene not an added one, it's possible to achieve the benefits without genetic modification; rather it can be achieved by traditional plant breeding techniques. This means that such mutant plants could potentially be introduced to commercial varieties very quickly.

One of the obstacles in finding a similarly impaired SAL1 gene in wheat is that wheat has been interbred and cross

Wheat is one of the world's most important food crops. Image courtesy of Bluemoose

Lisa Chew, Nok Pornsiriwong and Gonzalo Estavillo in a plant growth room. Lisa is working as a technician on a GRDC-funded project to isolate SAL1 mutants in wheat using molecular techniques. Nok's PhD project deals with the basic understanding of how SAL1 gene is involved in water movement across the plant.

cultivated for over six thousand years, resulting in a highly complex genome. To make matters worse, wheat carries between two and four copies of its DNA in each cell depending on the variety. Consequently, the scientists may have to find several different wheat lines that lack the different SAL1 genes in order to reach their goal of improved drought tolerance in wheat.

"The ultimate aim of this project is to develop wheat lines with improved drought tolerance and water use. The next step will be to identify wheat mutant plants lacking SAL1 genes identified by molecular biology procedures. We expect that these mutants should remain green, turgid and photosynthetically active, producing more leaves, flowers and seeds during mild to moderate water deficit."

If all goes according to plan, the researchers will begin to introduce these mutant characteristics into the elite wheat cultivars currently used in agriculture.

But it's not just crop production that looks set to benefit by this research. It may also be an important step in unravelling the function and mode of operation of different plant genes. The researchers are looking at what happens when they cross the drought resistant *sal1* mutant with another mutant strain known as open stomata 1. Plants carrying the open stomata 1 mutation are unable to sense the plant hormone Abscisic Acid (ABA) released during stress. As a result, they fail to close their stomata to restrict water loss during drought and perish rapidly in dry conditions. However, when crossed with the *sal1* mutant, the progeny have renewed drought tolerance. The researchers believe that studying the interplay of these two mutations may lead to vital clues about the complex action of ABA and the genes that control it.

Most breakthroughs in science come from multiple researchers and institutions working collaboratively and this SAL1 research is no exception.

"Our group is part of the Australian Research Council (ARC) Centre of excellence for Plant Energy Biology along with the University of Western Australia and the University of Sydney. We are also collaborating with Dr Crispin Howitt and other scientists at CSIRO Plant Industry and have received funding from the Grains Research Development Council for the wheat project. This brings together a wide range of complementary facilities and expertise and makes this project really exciting to work on."

The value of the Plant Energy Biology Centre and the ground-breaking work it performs was clearly reflected by a recent ARC decision to expand and extend the centres funding until 2013.

Passionate about plants

New Rural Assistance Scholarships Aim to Help Students from the Bush, fix the Bush

Australian agriculture and our native plant communities are currently facing a difficult period with drought, climate change and the propagation of pests all taking their toll. However Dr Adrienne Nicotra, a plant biologist from ANU, believes that with the application of the right science, we can make good much of the damage.

"We're fortunate to have many leading scientists from the fields of forestry, ecology, plant physiology and agriculture concentrated on the ANU campus, and also that we are in such close proximity to the CSIRO facilities at Black Mountain." She says. "But the key to success in any scientific program is people. Accordingly, we're very much on the lookout for promising students. Naturally we're keen to attract those with a high level of academic achievement, however over and above this, we want to attract young scientists who will be passionately motivated to develop scientific solutions to the current problems. We want to target students from rural areas in particular because we believe they will have direct experience of the current challenges facing plant sciences and strong desire to address them."

One of the current difficulties facing students from rural areas is the cost of interstate removal and travel to attend university. In an attempt to redress this problem, Dr Nicotra has initiated a program of sponsored rural assistance scholarships that help the brightest youngsters from the bush to come and study plant sciences at ANU. The first in what she hopes will be a series of these scholarships has been provided by the CSIRO Division of Plant Industry. Interested students are invited to see the website for further information . . .

http://cos.anu.edu.au/Plants

Dr Adrienne Nicotra

Profile of Lee Constable, First recipient of the plant sciences scholarship

Name: Lee Constable (First recipient of the plant sciences scholarship)

Origin: Galong, New South Wales

Current Degree: Combined science and arts degree

How did you come to be studying at the ANU?

I first learned about the ANU when I did a one week Siemens science experience with the university in year nine. A few years later I went to the ANU open day and felt very impressed. The reputation of ANU was a big deciding factor of my decision – I am aware that it's quite strong in the sciences/research area. It's also close to the CSIRO, where I hope to work at in the future.

How did you come across the plant sciences scholarship?

I found out about the scholarship at the ANU webpage, and I applied for it online. It was great as my academic score wasn't the sole deciding factor as with some other scholarships, but rather this one also considers my experiences and interests. As I grew up with my parents on a sheep farm, I've seen/been through droughts, learnt more about the environment and thus developed an interest in environmental and plant science.

What was the best feature of studying at ANU?

I truly appreciate the diversity of the education offered – apart from my environmental science classes I'm also taking drama and sociology, with my sociology class giving a fresh perspective on what we learn in environmental science. I'm also glad that my plant science scholarship doesn't limit me to studying only a specific field – as long as I'm doing the required subjects there actually isn't a problem with me cultivating other interests!

What has been the highlight of your ANU experience to date?

In our semester break I signed up for a course offered by the University of Queensland ('Asia/Pacific Tropical Forest Management and Extension Tour') that I found on the Fenner discussion board. Students of the ANU who are interested in this course would have to do a cross-institution enrolment with ANU's permission. I was finding ways to get the most out of my scholarship funds, so I decided to apply for this course. I then joined ten other students in a trip to the Philippines to look at forestry management for two weeks, and wrote a report on it.

How do you feel the ANU is preparing for your future?

The courses that we have are pretty hands-on – we've been on field trips which were fun and practical. My scholarship includes an internship opportunity with CSIRO that I'm looking forward to!

Dead Wood

Reversing a Tree Regeneration Crisis

It's long been known that paddock trees in much of Australia's temperate grazing region are not regenerating. With every year we lose a few more as the old trees die but nothing is coming through to replace them. In recent years there's been a growing realisation that the situation is rapidly evolving into a crisis.

"Under existing management practices, millions of hectares of grazing country, currently supporting tens of millions of trees, will be treeless within decades from now," says Dr Joern Fischer from the Fenner School of the Environment and Society. "And the loss of this tree cover is predicted to lead to massive declines in biodiversity and grazing productivity."

Dr Fischer's Sustainable Farms research group has spent the last couple of years documenting the extent of the tree regeneration failure and has been investigating if the situation can be reversed by changing land management.

"Although clearing has largely stopped, tree cover continues to decline because many existing trees are dying of old age, and few young trees are regenerating," says Fischer. "We studied a 1,000,000 hectare area in the Upper Lachlan catchment of New South Wales. Typical paddock trees are often over 140 years old, and in many locations, no young trees have regenerated for decades."

But it's not all bad news. The researchers also found that trees do regenerate under some management practices. For example, it was found that trees are more likely to regenerate in areas with low soil fertility or under high-intensity rotational grazing (as opposed to conventional continuous grazing).

"Our study identified a short list of management options for maintaining paddock trees," says Fischer. "In some areas, natural regeneration is unlikely in the short term, for example because there are few parent trees, or because soil nutrient levels are high. In such areas, scattered trees can be planted with re-usable tree guards that protect individual trees from livestock – some pioneering farmers are doing this already. Another option is to temporarily exclude livestock from a paddock prior to re-seeding it and resting it for several years – an approach successfully used by Greening Australia in the Canberra region."

Although clearing has largely stopped, tree cover continues to decline. Many old trees are dying, and few young trees are regenerating.

Ultimately, however, the study found that maintaining tree cover over vast areas cannot be done without Nature's help – that is to say via natural regeneration. Therefore, farm ecosystems must become self-sustaining, allowing for natural tree regeneration while also providing an income to farmers.

"Our findings suggest that self-perpetuating farm ecosystems with farms trees can be created by applying high intensity rotational grazing with long rest periods, and by phasing out fertiliser use," explains Fischer. "Even where these practices are adopted, changes in tree regeneration will not occur overnight. But unless significant changes in management are introduced now, old trees will continue to disappear, and opportunities for natural regeneration will continue to be lost."

"The future of Australia's paddock trees depends on urgent and widespread management action. While mature trees still exist, they provide regeneration nuclei throughout the landscape, thereby offering a window of opportunity to reverse the tree regeneration crisis."

More Info: http://www.pnas.org/content/106/25/10386.abstract

Dr Joern Fischer

Trees have ecological, economic and cultural value. They provide habitat for wildlife and shade for livestock, they assist with water infiltration into the soil, and they are iconic parts of the Australian landscape. Given the importance of maintaining tree cover, what can we do to reverse the crisis in tree regeneration that threatens to transform our landscapes in the coming years?

Plastic Plants

David Salt

Assessing the Threat of Weeds with Phenotypic Plasticity

Amy Davidson is into plastic weeds. Well, not so much weeds made of plastic as invading plants that possess phenotypic plasticity. And she believes a better understanding of phenotypic plasticity in plants will help us manage weeds in a world undergoing climate change.

"Phenotypic plasticity is when the genotype of an individual plant is able to respond differently to varying environmental conditions," Amy Davidson, a PhD student in the Research School of Biology, explains. "In other words, the plant can respond with greater flexibility as conditions change to maximise its chances."

A plant's genotype is the information it carries in its genes. Its phenotype is how this information is expressed as the plant grows. Measuring a plant's plasticity, however, is far more challenging than simply measuring its leaves or the size of its seeds. It requires the measurement of a range of physical and physiological attributes of one plant and then comparing it with these same attributes with another plant species with similar genes to see how they respond to environmental conditions as they change.

"It's long been believed that weeds might be more plastic than native species," Amy says. "Indeed, it's this property that enables them to do so well, to be an effective invader.

"When a weed comes into a new area, a place where it hasn't evolved, it often arrives with only a small number of individuals and not a lot of genetic diversity. So, it's been postulated that one of the reasons weeds do so well, especially in novel or changing environments, is that they are more plastic than the natives already in that area."

As part of her research, Amy has trawled through the literature looking at plasticity between native plants and closely related invasive plants. To her surprise, she found that for many plant species, and regardless of what treatment the native and the invasive were put through, the invasive species were always significantly more plastic than the native species.

Plasticity looks like being an important characteristic of invasive plants, but to explore how it works, in what circumstances it comes into play, Amy has set up her own growth experiments using two species of a small herb from the geranium family.

"I'm looking at an Australian native called *Erodium crinitum* and comparing it with the exotic weed *Erodium cicutarium*, which is native to the Mediterranean. Both species co-occur around Canberra and can be found growing west of here out to Mildura. That's great for me because it means they are found along a gradient of decreasing rainfall.

"So, I'm growing several hundred plants in a glasshouse under five different water treatments that represent some of the

Ms Davidson is growing several hundred plants (natives and invasive weeds) and measuring a range of attributes under different watering regimes.

rainfall regimes they experience in the wild or may experience as the climate changes. These range from frequent water, more than they would experience in the wild, down to only watering when the plants gets to wilting point (with a range of treatment in between these extremes)."

To examine and compare plasticity, Amy will measure her test plants for a range of characteristics including phenology (timing and duration of flowering and seeding), reproductive effort (how many seeds they produce and how viable those seeds are), leaf shape and area, physiological measures like stomatal conductance and photosynthetic rates, and basic anatomical measures such as rooting depth, root biomass, shoot biomass and leaf and seed biomass. She'll see how the native compares with the invasive under different water availability treatments and, from this, assess their plasticity and fitness.

"There is some evidence to suggest that plants with phenotypic plasticity will cope better with novel conditions that might be increasingly experienced with climate change," Amy says. "In south east Australia one of the biggest changes we'll be dealing with is changing rainfall, and especially lower rainfall and more variable rainfall.

"So, my starting hypothesis is that the native species are used to slightly more predictable rainfall so it would have specialised, it would be locally adapted along that natural rainfall gradient. The invasive plant, on the other hand, hasn't had as much time to evolve so it might be dealing with that natural rainfall gradient by being phenotypically plastic, and that's what I'm testing in the glass houses right now."

"This knowledge might provide us with an idea of when being plastic is particularly beneficial for an invasive species, and that's something we need to take into consideration. Often when we're mapping out where we think invasive species will be able to move to, we don't take into account phenotypic plasticity. Also if we understand under which circumstances phenotypic plasticity is likely to be an important factor in the invasion process, then it's something we can start to look for."

Amy Davidson with her native and invasive erodiums in the School's glasshouses.

Improving our capacity to understand and manage weeds could be vital in a climate change world in which novel environments will be increasingly common. Weeds already cost Australian farmers over $4 billion every year (in terms of the cost of control and reduced crop yield), as well having enormous impacts on many native plant and animal species. Under climate change, many scientists and managers believe that the impact of weeds will dramatically rise because of their ability to adapt to novel environments; something many crop and native species don't possess.

So plastic weeds may be on the rise, and plasticity is one aspect of plant biology that we need to pay more attention to. Amy Davidson's work on a little geranium weed should give us a much better handle on what it means to be plastic.

Can DNA Packaging in Plants

Regulating Pigment Composition and Plant Architecture

Carotenoids are the second most abundant class of coloured organic pigments on Earth. They tend to absorb blue light giving them a characteristic red, orange or yellow colour. Carotenoids serve a central role in the chemistry of photosynthesis and are found in many plants, algae, fungi and bacteria. They are what give many fruits their distinctive coulors and are also responsible for the vibrant hues of autumn leaves.

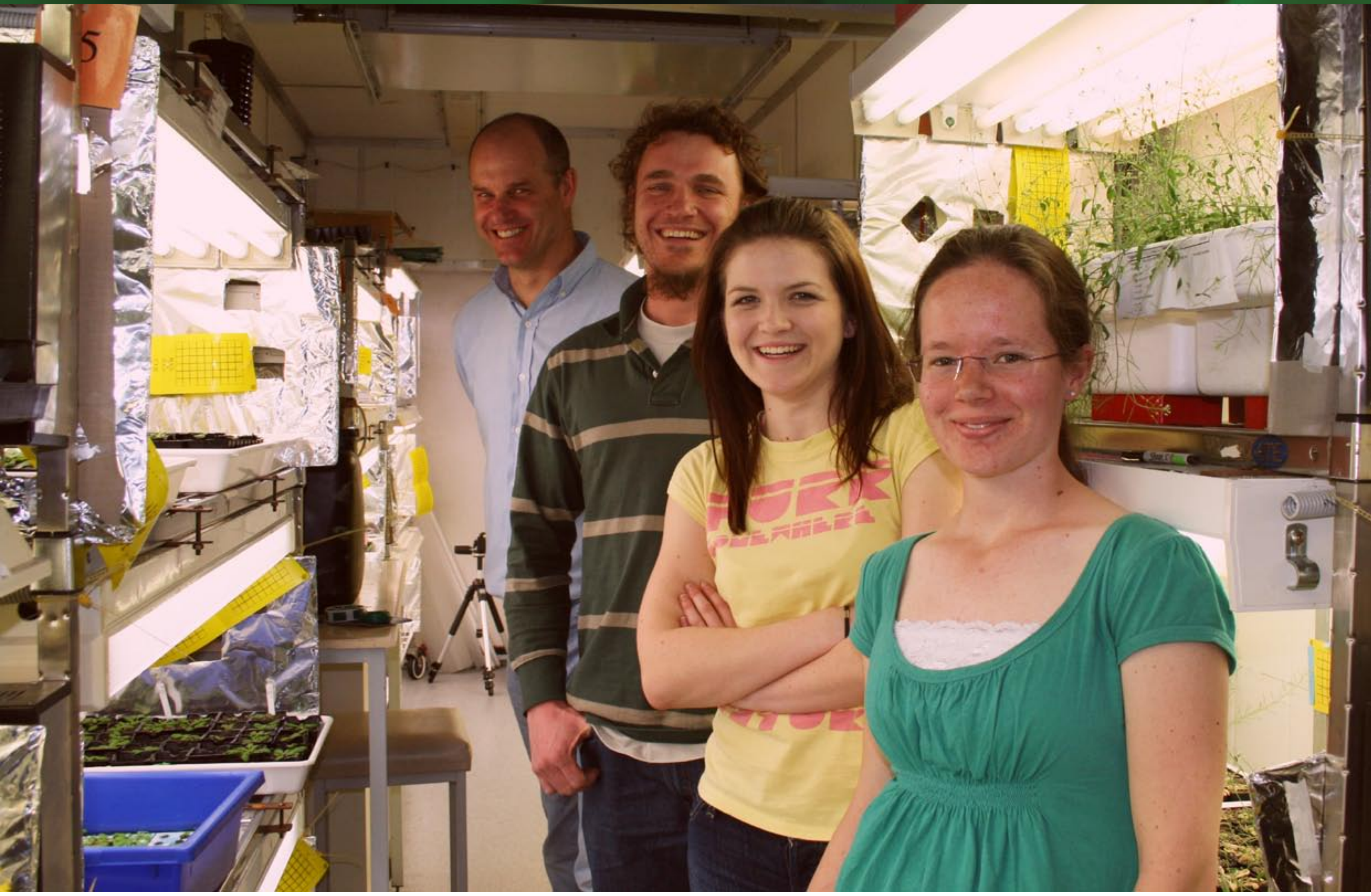
Beyond their role in plants, Carotenoids are also vital to the biochemistry of most animals including humans. However, unlike plants, animals do not directly produce carotenoids, so they have to get those they need from their diet. Lack of β-carotene, a vitamin A precursor, can lead to deterioration of the immune system and blindness. Consequently, fruit and vegetables are an essential dietary requirement for humans. But not all food colours are due to carotenoids, so not all plants provide an adequate source.

Dr Christopher Cazzonelli is a Research Associate at the Research School of Biology, ANU. He is a member of the Pogson lab in the ARC Centre of Excellence in Plant Energy Biology - a cutting edge research centre focused on better understanding the way in which plants produce and use their energy systems in response to environmental change.

Professor Pogson gave Dr Cazzonelli the challenge of finding what limits the production of carotenoids in plants and it wasn't long before he had identified a chromatin-modifying gene, SET DOMAIN GROUP 8 (SDG8). He found that it regulates carotenoid composition as well as flowering time, seed set, germination, root development and shoot branching.

Dr Cazzonelli says, "Loss of function of SDG8 limits production of a carotenoid called lutein, (the same compound that prevents age-related macular degeneration of the human eye.) Furthermore, we have found preliminary evidence of novel hormonal-like roles for carotenoids in the differentiation of plant stem cells into roots, leaves and flowers."

A range of selectively bred carrots exhibiting different Carotenoid pigmentation. Image: Stephen Ausmus.



Professor Barry Pogson, Dr Christopher Cazzonelli with students Andrea Roberts and Alice Burgess in the Plant Growth Room

Such modifications in cell structure that arise from external factors rather than directly from the cell's DNA are known as epigenetic changes and are becoming an increasingly important area of research.

In response to environmental pressures, organisms have evolved to reversibly modify DNA-binding proteins. These proteins regulate how DNA is packaged within the nucleus of the cell. This affects gene expression and cell function without changing the original DNA sequence, creating a 'memory process'.

Unlike genetic modifications, which lead to the inheritance of genetic information, such epigenetic modifications can mediate the transmission of an active or silent state of gene expression without altering the primary DNA sequence. As these modifications can be reversible, they can form the basis of a controllable regulatory mechanism.

The essential roles of carotenoids, as well as the chromatin-modifying nature of SDG8, have opened a new door towards understanding regulatory mechanisms that control plant development. The team are now investigating when and why epigenetics regulates carotenoids in fruits and cereals and how this effects plant development.

This further research has many possible applications and could one day help developing countries by preventing the medical problems associated with gross Vitamin A deficiency.

Dr Cazzonelli found inspiration and a mentor whilst growing up on the Tablelands in Far North Queensland. In between racing dirt bikes around his parents' crayfish farm, his neighbour would excite him with stories about molecular biology and its potential. He says, "Our discussions were complex: proteins, DNA, chromosomes, things that we didn't know a lot about in the late eighties and because it was so hard, I figured that if I could study it and be good at it, that I would have an edge, an advantage out there in the job market, so I took that chance and it has paid off."

He now has many peer-reviewed data papers including a publication in Plant Cell, the plant biology research journal with the highest number of citings. However, he plays down his blossoming scientific career by saying, "I enjoy working as a Plant Molecular Biologist, while I am not racing motocross!"

Flowers That Tell Lies

Tim Wetherell

The Extraordinary Tricks Used by Orchids to Lure Pollinating Insects

Orchids are far more common that many people might think. In fact they account for about one in ten of all flowering plant species. Some of the most famous ones grow epiphytically on rainforest trees but there are many others that simply grow on the forest floor amongst the other terrestrial plants.

Like many flowering plants, most orchids rely on insects to carry pollen from one plant to another. However, whilst most flowering plants offer a food reward to their pollinators, almost a third of orchid species resort to deception. In many cases this is a simple lie; the flowers look and smell like they would bear nectar but contain none at all. However, in other orchids, this deception can take quite bizarre forms such as sexual deception.

To achieve this, the orchid produces strange flowers with dark globular growths on one petal that may bear a superficial resemblance to a female insect. However, in the insect world, good looks alone are not enough, the female's pheromone scent being the most important attractant for males. Accordingly, to complete the deception, the orchid flower produces molecules that mimic these pheromones. The scent, and to a lesser extent the flower's appearance, entice the male insects to land on it. When it does so, the orchid's unusually large pollen mass becomes attached to its body. Some orchids even go so far as to temporarily trap the male insect by closing their petals once it lands. To escape the insect has to squeeze past the sticky pollen bundle.

Of course given the diversity and abundance of sexually deceptive orchids, there has to be a mechanism by which they can ensure that the pollen from a particular orchid finds its way to another plant of the same species. Generally, this is achieved by each species of orchid targeting a single species of local insect, which in turn has its own specific pheromone.

Professor Rod Peakall from The Australian National University is one of the world's leading authorities on orchid pollination. Together with his research group, he's currently conducting a study of Australian terrestrial orchids that use sexual deception to lure pollinating insects.

"When we began our study of some 30 orchid species growing in the southern half of Australia, we imagined that we might find 30 different combinations of pheromone used to attract the pollinating insects." He says. "In fact so far it has turned out to be just four communication channels." This raises the question, how do orchids ensure that they don't attract the pollinator insects of different orchid species which could lead to hybridisation?

Professor Rod Peakall

The key to avoiding such hybridisation turns out to be locality. If two species live in geographically distant habitats, there is no danger of inter-pollination so they can both use the same pheromone mimic to attract the same insect species at the same time. "It's a bit like FM radio. Many different stations can transmit on the same frequency providing they are in widely separated parts of the country." Dr Peakall explains. "And of course conversely, if the two orchids share the same location, then they have to use a different pheromone mimic.

Apart from shedding light on the behaviour of orchids, this work has wider implications for evolutionary biology and especially for our understanding of speciation; the process by which populations of living things diverge into separate species that are no longer able to effectively interbreed. One of the most important mechanisms driving speciation is geographical isolation. Some members of a population become separated by large distances perhaps as the result of environmental changes or simply by chance. Each sub population then further evolves to suit its new habitat and eventually, the two groups become so genetically distant they form separate species.

However there is another more contentious speciation mechanism called sympatric speciation in which some new species form without this geographical separation. Dr Peakall believes that some of the orchid data point strongly to this possibility. In this case, it's the highly specific relationship orchids have with their insect pollinators that could drive the speciation. A small mutation can subtly change the orchid's pheromone mimicking molecule, for example it may become an isomer of the original (same chemical composition but different structure). Insect response to pheromones is highly specific, and such a change in the flower may change the pollination insect species it attracts. From that point on the two orchid populations would become effectively isolated from each other even though they still inhabit the same physical place. If this turns out to be the case, it will be one of the very few cases of sympatric speciation that has been directly observed.

Say it with flowers - it doesn't have to be true! Some species of orchid use elaborate and devious sexual deceptions to lure insect pollinators.

Feed the World

Trying to Unlock the Potential of C_4 Rice

The United Nations Food Agency recently announced that over the coming 40 years the world's food production will need to rise by 70% in order to feed the growing population. Failure to achieve this is likely to result in widespread famine. This in turn, may well lead to unrest that spreads well beyond the borders of the most affected nations, so in reality, it's likely to become everyone's problem. The difficulty the world faces in addressing this is that most of the viable agricultural land is already used to capacity and production is limited by other factors such as water availability. The general consensus amongst scientists is that the only practical way to avert catastrophe is to enhance the photosynthetic yield per leaf area of food crops. In other words, to create more efficient plants.

Most plants, including many staple foods like rice, turn sunlight into sugar using what's known as the C_3 photosynthetic pathway. In this process gaseous CO_2 is combined with an enzyme called RuBisCO to create sugar. However RuBisCO can and often does, combine with oxygen instead of CO_2, leading to a loss of efficiency particularly at higher temperatures.

Some more recently evolved plants have developed an alternate photosynthetic pathway called C_4 that avoids this loss of efficiency by using some additional chemistry to saturate the RuBisCO enzyme with CO_2 and starve it of oxygen. This avoids wasteful oxygen combinations and under most environmental conditions, leads to a higher sugar yield in the plant. Scientists believe that if they can introduce this C_4 photosynthesis to rice, they may be able to create cultivars that produce more crop per area than existing rice without consuming more water or fertilizer.

One scientist studying the possibilities of C_4 rice is Professor Susanne von Caemmerer of the Research School of Biology.

Professor Susanne von Caemmerer and technical officer Scott Kwasny in one of the greenhouses

Professor von Caemmerer is working on a project with the International Rice Research Institute, sponsored by a $10m grant from the Bill and Melinda Gates foundation. The ultimate aim of this work is to create C_4 rice with a substantially better yield than existing plants, but this is a hugely complex task requiring multiple steps.

The basic idea is to look at millions of mutant seedlings of both C_3 rice and C_4 sorghum. Scientists expect the random mutations to cause some of the rice to move towards the C_4 pathway and some of the sorghum to partially revert to the C_3. If they can identify which specimens these transformations take place in, they can analyse their genomes and compare them to conventional rice and sorghum. Seeing both the C_3-C_4 and C_4-C_3 switch should help them to isolate the genes responsible for the two photosynthetic pathways.

It might sound fantastically unlikely that random mutations would produce a switch between photosynthetic pathways, but there are some good scientific reasons to think otherwise. "We know from studying various C_4 plants that they have evolved from C_3 plants on at least 40 separate occasions. So it seems highly probable that the jump isn't a huge one in genetic terms." Professor von Caemmerer explains. "We also know that the basic suite of enzymes involved in the biochemistry is essentially the same in C_3 and C_4 plants, so again we're not talking about needing to introduce major changes to the plants genes."

The plants will be grown at IRRI and at the High Resolution Plant Phenomics Centre co-located in Canberra at CSIRO Plant Industry and The Australian National University. This facility enables vast numbers of plants to be cultivated under highly specific conditions of atmosphere, water and nutrients.

But having grown a million seedlings, how do you pick out those with C_3 or C_4 pathways?

C_4 plants can concentrate atmospheric CO_2 within their leaf structures, so they can grow in low CO_2 concentrations. C_3 plants on the other hand, actually lose CO_2 from their leaves under concentrations below about 50 parts per million, ultimately leading to the plant's death. By growing seedlings under low CO_2 concentrations, the scientists can pick the surviving rice, which is likely to be displaying at least some C_4 characteristics. The can also rescue any dying sorghum, which is likely to have partially reverted to C_3.

In both cases the plant's anatomy will also give clues to the pathway it's using because C_3 plants have a different leaf structure to C_4. In a C_3 plant most of the chlorophyll lies in the tissue between the vascular bundles. In C_4 plants it tends to cluster around the bundles themselves and in addition, the bundles are more numerous and more closely packed.

Once a subset of seedlings displaying a switch in photosynthetic characteristics have been identified, they will then be subjected to more advanced scrutiny such as isotopic analysis. RuBisCO discriminates strongly against the isotope carbon 13. In C_3 plants this means that air flowing over the leaves tends to become carbon 13 enriched as carbon 12 is depleted. However, the CO_2 concentration mechanism of C_4 plants has the tendency to negate this effect by effectively feeding the enzyme with whatever carbon comes to hand, 12 or 13. As a result, air passing over C_4 leaves has significantly less carbon 13 than that passing over C_3 leaves. This gives scientists a very clear indicator of the different photosynthetic processes occurring in a particular plant.

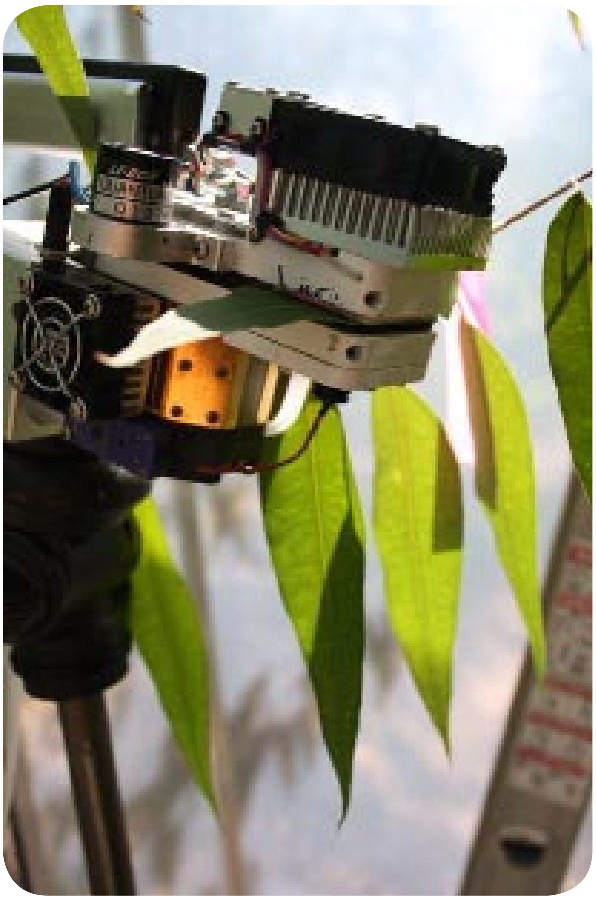
"Ultimately, this is a gene discovery project. We're hoping to isolate mutants that appear to switch photosynthetic pathways. What we can then do is look at the genome of those plants and try to identify which genes are responsible for C_4. This would be a huge help to another arm of the project in which scientists would directly splice those genes into existing rice cultivars," Professor von Caemmerer says.

Many people depend on rice for food, and go to extraordinary lengths to cultivate this important crop. Rice terraces hewn out of mountain slopes in the Philippines make use of every scrap of available land.

Growing Trees in Future Tents

Probing the Response of Plants to Climate Change

How will our plants grow in a greenhouse future? It's projected that our atmosphere will contain elevated levels of carbon dioxide (CO_2). Carbon dioxide is essential for plant growth, so does having more of it around mean plants will grow faster? And if they do, will they absorb greater amounts of carbon from the atmosphere? The answers to these deceptively simple questions have massive implications for agriculture and our understanding of climate change. Plant scientists in the Research School of Biology (RSB) (in collaboration with partners at the University of Western Sydney) are attempting to throw more light on these issues by studying how trees respire when raised in an atmosphere of the future. This is achieved by growing a whole tree in a massive transparent tent – a Whole Tree Chamber – in which CO_2 is present in concentrations expected to be experienced in 50 to 60 years time.



Measuring respiration rates in leaves on trees being grown in atmospheres of the future

Understanding the interaction of CO_2 and plants is central to our understanding of the global carbon cycle. Humans currently release around 6-7 gigatonnes of carbon into the atmosphere every year but plants take up around 20 times that amount through photosynthesis. A significant proportion of this carbon is then released in plant respiration, the process of growth that uses the stored energy captured by photosynthesis.

"To effectively model the future carbon economy we need a thorough understanding of how plants photosynthesise and respire at elevated levels of CO_2," says Associate Professor Owen Atkin from the Functional Ecology Group at RSB. "While there are many ways of estimating this, one of the best is to grow a whole plant in an atmosphere with elevated CO_2 levels. Other methods include sealing up leaves and branches in bags containing a modified atmosphere but the gold standard is looking at the whole plant."

And this is exactly what's being attempted in the Hawkesbury Forestry Experiment, a unique national facility that has been established at the University of Western Sydney (UWS). It involves growing blue gum trees, a fast growing plantation species, in large chambers in which the CO_2 and moisture can be controlled.

"The trees were planted in 2007 and they were placed in chambers which enabled the environment around individual trees to be manipulated," explains Atkin. "They have 12 chambers, six of which have ambient atmospheric CO_2 concentrations and the other six have elevated CO_2 concentrations. The elevated levels simulate CO_2 concentrations that we'll have later this century, around 640 parts per million.

"But the experimental facility is looking at more than just CO_2 levels because one of the expected impacts of climate change is an increased frequency of drought. So the experiment will also look at this. In the ambient and elevated chambers half the trees have been subjected to drought conditions, and the other half to a well watered regime."

While the experimental facility is being managed by UWS and associated partners, it is a national resource established to study a global phenomenon. Researchers from around the country have been invited to participate and apply their special research strengths on the encased trees. Associate. Professor Atkin's interest is in plant respiration under varying environmental conditions, and the opportunity to work with the trees has allowed him to fill in an important information gap in modelling carbon exchange and respiration.

"The process of respiration releases a huge amount of CO_2," says Atkin. "Anywhere between 20-80% of the carbon that

Owen Atkin is attempting to understand plant respiration under elevated levels of carbon dioxide.

comes in through photosynthesis is respired everyday by whole plant respiration. Half of it takes place in leaves and the other half largely happens in the roots. So it's a big player in terms of the carbon economy of an individual plant, and it's also a big player from the point of view atmospheric CO_2 concentrations.

"Most of the global circulation models that predict future climate have a photosynthesis component and a respiration component. But the respiration component has several weaknesses in its underlying assumptions. For example, one assumption is that respiration increases exponentially with rising temperature but we know that it doesn't. Respiration doesn't just keep going up with temperature; it acclimates, it seasonally shifts its temperature response curve as you get a warming."

"And large scale models are unable to predict accurately respiratory rates that are occurring in forest trees. Without that we can't properly model how quickly those trees will grow and the contribution those trees will make to atmospheric CO_2 either in a negative or positive way."

"So, it's extremely important that we understand how environments impact on this process of respiration in plants. This experiment was very useful because it enabled us to access whole plants that were going to experience future elevated levels of CO_2. Plus we could study the impact of drought."

"I was excited to take part in the Hawkesbury Forestry Experiment because it's the only facility of its type in Australia. It enables us to quantify the rate of carbon uptake by entire canopies through time. And the Whole Tree Chambers also

have a partition between the above and below ground part of the tree that allows them to separate the shoot processes from the soil and the roots so we can quantify CO_2 release from the below ground part as well."

Working with ANU-based postdoctoral fellows Kristine Crous and Joana Zaragoza-Castells, and colleagues at UWS (Professors David Ellsworth and David Tissue) Professor Atkin has been travelling up to visit the enclosed trees every 4-6 weeks. Each visit lasted several days during which they measure respiration rates from 5am in the morning through till 11.30pm at night.

They found that the trees growing with elevated CO_2 levels were exhibiting elevated rates of photosynthesis and were respiring at higher rates. This was expected but they also found that the leaves were thicker and there was a change in leaf chemistry with lower levels of nitrogen being present.

"We've found that elevated CO_2 affects the plant's respiration rates," explains Atkin. "It enhances it on an area basis, though not so much on a mass basis.

"Drought has a big impact on respiration on elevated and ambient CO_2 trees. Significantly, the decrease under drought was quite pronounced under elevated CO_2. Under drought conditions, respiration rates come right down to the same basal rates of the ambient level plants. So, they both have dropped their rates, but one set of trees (the plants growing in elevated CO_2) start a bit higher."

"It makes sense when you consider that the plants have to respire; if the leaves don't respire they're dead. So there's a certain basal rate they must maintain in order for their tissues to remain viable. Remaining viable during drought means that when water becomes available they can start taking advantage of it. In a modelling context, drought has a much bigger impact on the respiratory fluxes of a CO2 elevated plant; they start from a higher point but they come down to a similar point. These kinds of empirical data are critical if our models are to be valid."

The first crop of trees grown in the enclosures has now been harvested and the hope is that the Hawkesbury Forestry Experiment might grow several more crops over the coming years to better explore trees and carbon exchange.

"Carbon sequestration is a big strategy for managing global carbon but there's so much we don't know on how climate change impacts on the rate of carbon movement in and out of trees," says Professor Atkin. "Working with experimental facilities such as this will be critical if our efforts to effectively manage carbon with trees works over time."

The Hawkesbury Forestry Experiment is growing whole trees in chambers in which future atmosphere's can be simulated

A perspective on Plants

By Dr Jeremy J Burdon - Chief of CSIRO Plant Industry

(Excerpt from Dr Burdon's Address the Graduation Ceremony at The Australian National University)

It is an amazingly exciting time to be involved in plant science – tremendous challenges but also tremendous opportunities!

On the one hand, we face a series of significant, even daunting, challenges – challenges that ultimately can be traced back to the world's continuing population growth and the natural expectation that most people have to aspire to a higher quality of life.

The world's current population of ~6.3 billion will almost certainly rise to greater than 9 billion by 2050. This coupled with a rapidly increasing middle class in developing countries, inevitably results in a need to increase the world's food supply by around 50% if we are to prevent mass starvation. Put another way, between now and 2050 we will need to have produced as much food as has been produced since the dawn of civilization until now!

Furthermore, this has to be achieved against a backdrop of an increasingly warm, variable and at least in our part of the world, drier environment. That is, we need to achieve very substantial increase in food production while simultaneously significantly reducing the human environmental footprint.

Pretty daunting? Yes and No. Yes – in that, as a species, we do tend to leave responding to threats to the last possible moment... No – in that with rapidly advancing technology and the skills that the new generation of scientists will bring, what we can achieve during your life-time will be essentially constrained by our imaginations.

The application of genetic engineering to cotton has largely eliminated the need to spray fields with tons of insecticide to counter the threat of the cotton boll worm moth. Image: United States Department of Agriculture

It is truly an amazing time in science and there are many reasons to believe that the world can effectively respond to these challenges – all that is needed is the commitment.

Why do I believe so strongly in our ability to respond? Let me give you a feel for the palpable excitement that is out there generating new approaches to current problems. Over the last 15-20 years plant biology has been going through an amazing revolution that shows no sign of abating – indeed, many fields are moving so quickly that they are virtually unrecognizable to their state when I sat where you are some 33 years ago.

Advances in agriculture and the environment all now hinge upon a unifying challenge – understanding the pathway whereby genome sequences are translated into important whole-of-system characteristics of form and function, the similarities and differences of these processes between animals and plants, and the way these steps interact with disease causing organisms, will open the way to custom-designing organisms for specific food, health and environment purposes.

I'm especially proud of one particular example of the environmental benefits such approaches can bring. This concerns cotton production in Australia. Cotton is an interesting fibre crop that essentially has no natural resistance to the cotton boll worm moth (*Heliothis sp.*) that eats leaves, buds, flowers and developing bolls. In the 1980s and 1990s this pest was a scourge to cotton production in Australia – in bad years, without control, whole crops were destroyed. The only solution was Integrated Pest Management coupled lots and lots of insecticide sprays. Genetic engineering has provided an important solution to this problem. Incorporation of a gene derived from a bacterium (*Bacillus thuringiensis*) has conferred resistance to the boll worm on cotton plants – two such Bt genes have been incorporated in order to reduce any possibility of evolution to overcome the resistance by the insect. This technology has allowed a greater than 80% reduction in the use of insecticides.

Scientifically, Australia is a small country – it carries out only 1-2% of the world's science but Australia should be immensely proud of its scientific achievements and capability. These achievements are directly attributable to the quality of our scientists and their training. The students of today are the future generation of this chain of progression and like the current one will have a chance to stand on the shoulders of giants! I know that with your skills, enthusiasm, commitment, and drive Australia's future is in safe hands!

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