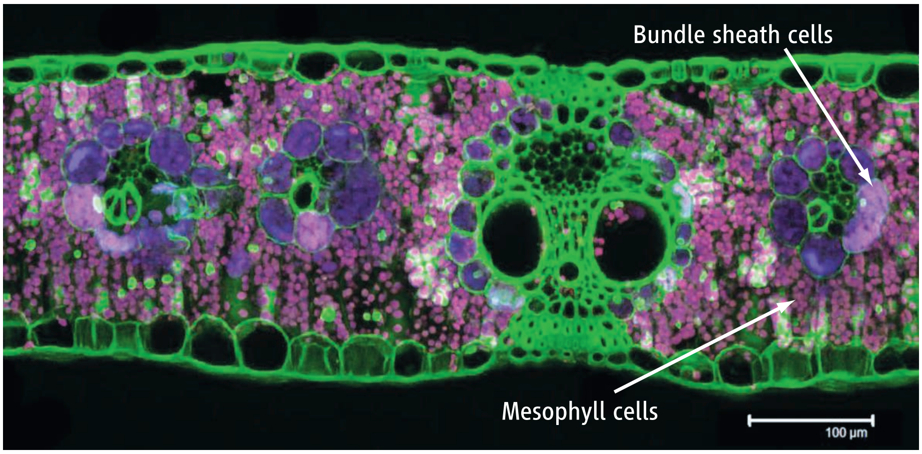
IMAGING

With 'Phenomics,' Plant Scientists Hope to Shift Breeding Into Overdrive

MELBOURNE, AUSTRALIA—Last May, a scrawny grass, *Brachypodium distachyon*, joined the exclusive club of plants whose genomes have been sequenced. *Brachypodium* may look unassuming, but under the hood it is a geneticist's dream. It has a short life cycle and a small genome with one pair of chromosomes (wheat, for instance, has three pairs) that readily reveals the effects of genetic modification. In short, the temperate grass is a superb model organism for cereals like wheat and rice and for biofuels like switchgrass. But *Brachypodium*'s genome alone cannot revolutionize plant breeding.

Enter plant phenomics. Borrowing imaging techniques from medicine, phenomics offers plant scientists new windows into the inner workings of living plants: infrared cameras to scan temperature profiles, spectroscopes to measure photosynthetic rates, lidar to gauge growth rates, and MRI to reveal root physiology. "Phenomics will give plant scientists the tools to unlock the information coded in genomes," says Mark Tester, director of the Australian Plant Phenomics Facility (APPF), a new $40 million venture with headquarters in Adelaide.



A-maizing transformation. In this maize leaf, laser confocal microscopy reveals a clear distinction between high activity of photosystem II in mesophyll cells (pink fluorescence) and low activity in bundle sheath cells (purple)—a distinction typical of C4 plants. The green fluorescence comes mainly from lignin in cell walls.

Institutes worldwide are racing to build facilities with instrument arrays that can scan thousands of plants a day in an approach to science akin to high-throughput DNA sequencing. "This will allow plant physiology to 'catch up' with genomics," says Tester. APPF, the first national lab of its kind in the world, consists of two nodes. One is a High Resolution Plant Phenomics Centre (HRPPC) in Canberra, which opened last week. A debut project of the center is an international collaboration to screen *Brachypodium* variants for drought-tolerance and for less lignin in their cell walls. The second node is the Plant Accelerator in Adelaide, a screening facility that Tester will run and aims to get online by December.

"Australia is leading the way," says David Kramer, a spectroscopist at the Institute of Biological Chemistry at Washington State University, Pullman. But other countries are ramping up fast. In Germany, for example, the Institute for Phytosphere Research (IPR) in Jülich in 2007 established the Jülich Phenomics Centre, which carries out a variety of screens and is developing root imaging. And the Leibniz Institute of Plant Genetics and Crop Plant Research in Gatersleben is carrying out high-throughput screening on crops such as barley and wheat using instruments such as infrared cameras to chart transpiration and fluorescent microscopy to assess photosynthesis.

From feel to phenomics

Plant breeders are known for their "feel": the ability to select subtle traits that enhance a plant's performance. They might key in on the way a plant curls its leaves, for example, or a particular shade of green whose significance escapes the uninitiated. Such craftwork delivered enormous agricultural gains through the mid 1990s. But with yields of many crops having hit plateaus, green thumbs are no longer enough. Modern plant breeders need the equivalent of a watchmaker's magnifying glass and tweezers to tinker with complex and intertwined traits. Phenomics, says Uli Schurr, director of IPR, promises to usher in "precision agriculture and predictive breeding."

One trait Australia has in its cross hairs is salt tolerance. High salinity affects one-fifth of the world's irrigated land and two-thirds of Australian cereal crops. But selecting plants for salt tolerance has generally flopped. "We can end up with plants like mangroves that are salt-tolerant but slow growing and not much use," says Tester. He and Rana Munns of CSIRO Plant Industry in Black Mountain, Canberra, recently found that salt tolerance is connected with a plant's ability to resume growth after osmotic shock—the shutdown in cell growth occurring fractions of a second after a plant is exposed to high salt concentrations.

Exploiting that trait, Tester's lab earlier this year used a three-dimensional camera to record minute changes in growth responses after wheat plants transplanted into salty soil went into osmotic shock. After crossing varieties and laboriously screening hundreds of plants, one of Tester's Ph.D. students, Karthika Rajendran, appears to have pinpointed a gene that helps plants resist osmotic shock.

Such mind-numbing screening will be automated and sped up when the Plant Accelerator roars to life. It will have a throughput of 2400 plants a day—10 times the capacity of current labs. Plants will travel by conveyer belt to stations that measure growth rate and color, a sign of tissue health.

Also expected to get a phenomics boost is an effort to replace rice's inefficient C3 photosynthetic pathway with the C4 pathway found in maize and 40 other plant species. For the same input of water and nitrogen, maize produces twice the carbohydrate content of rice. Researchers have tried to assemble the C4 pathway in rice using maize enzymes, but the efforts failed, perhaps because rice's subcellular structure prevented the enzymes from working in synchrony.

Phenomics tools can provide snapshots of cellular structure and diagnose steps along the way toward C4 metabolism in live plants. The International Rice Research Institute (IRRI) in Los Baños, Philippines, is screening rice varieties for those with a cellular architecture best suited to house the C4 enzyme assembly. In C4 plants, mesophyll cells turbocharge photosynthesis by delivering carbon dioxide

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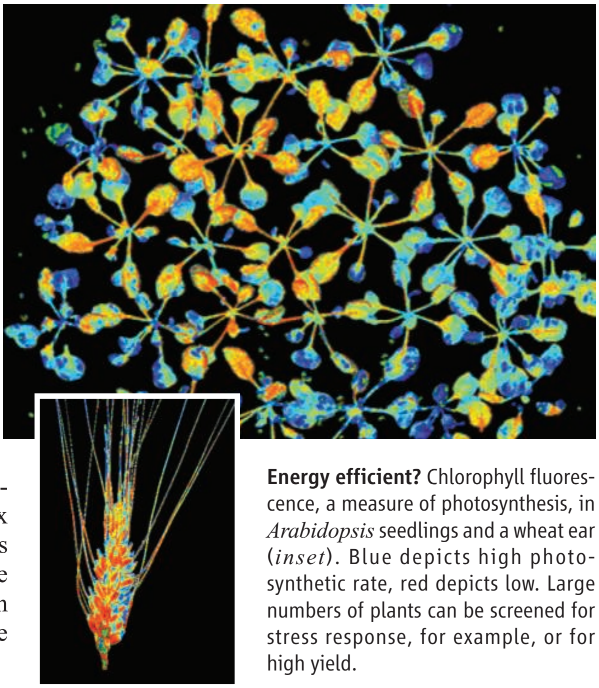
at 10 times atmospheric concentration to sugar-producing bundle sheath cells that surround the veins. For this transfer to work, there can be no more than three to four cells between the veins. IRRI's initial screens are for rice varieties with narrower spacing between the veins. Promising varieties will be shipped to HRPPC, which will use fluorescence microscopy and other tools to interrogate the plants. One approach is to look for a fluorescent signature from a complex of light-absorbing molecules called photosystem II: If these molecules' activities are muted in bundle sheath cells, it means the plant is becoming more C4-like.



Energy efficient? Chlorophyll fluorescence, a measure of photosynthesis, in *Arabidopsis* seedlings and a wheat ear (*inset*). Blue depicts high photosynthetic rate, red depicts low. Large numbers of plants can be screened for stress response, for example, or for high yield.

Kramer's lab in Pullman, meanwhile, is examining the split-second reactions that capture some energy of impinging sunlight while dissipating more than 80% to prevent damage. "If we could reduce this regulatory loss by 1%, we might double yields," he says.

Plants vary in how much light they dissipate. The photosynthetic rate of giant cane (*Arundo donax*), a potential biofuel source, is many times that of rice. Most crops are less efficient and "far too conservative for biofuels use," Kramer says. "They're playing it too safe."

Breeders have never seriously attempted to rev up the photosynthetic rate, says Kramer. Indeed, some high-yield rice varieties have reduced photosynthetic rates. The problem is that the switches that set the photosynthetic rate are poorly understood. To penetrate this mystery, Kramer plans to use the equivalent of a car engine dynamometer: a spectrometer that gauges the photosynthetic engine. The cogs of the engine—carotenoids, plastocyanins, and cytochrome complexes—emit unique spectral signatures in their excited states.

Kramer hopes to probe the "wear and tear" costs of photosynthesis with an "idea spectrometer," a device his group designed that is inspired by the "tricorder" of *Star Trek* fame. At the moment, the spectrometer, the size of a pint of beer, must be wired to a leaf; the goal is to be able to wave it over a plant like the fictional tricorder. Kramer says he would freely provide the device to colleagues to compile a global database of plant performance. "We can push our crop plants harder," says Kramer. "The question is how far."

Kramer and other adherents think the emerging discipline of phenomics will help foment the next green revolution. We now have the tools "to make quantum leaps in crop breeding," says plant physiologist Robert Furbank, director of HRPPC. "These are the tools we need to feed and fuel the world." **–ELIZABETH FINKEL**

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SCIENTIFIC PUBLISHING

Data Integrity Report Sends Journals Back to the Drawing Board

It seemed like a good idea: With digital data routine in nearly every scientific field, and growing concerns about doctored images and demands to share data, why not convene a set of experts to come up with general data-handling guidelines? But a National Academies panel found this task impossible. Instead, its report, released today, offers broad principles for dealing with data but calls on disciplines to work out the details themselves.

One trigger for the study was a particularly egregious case of scientific fraud: the faking of stem cell data by South Korean researcher Woo Suk Hwang, including cut-and-pasted cell images in a 2005 paper in *Science*. Faced with other examples of data manipulation, a group of journal editors asked the academies for advice in 2006. Academies officials added a second controversy they considered related: demands from a global-warming skeptic in Congress for data from the scientists who published the so-called hockey stick paper in 1998 in *Nature* that shows rising global temperatures since 1900. Then the academies convened 17 experts in fields from physics to sociology to look at issues of treating, sharing, and archiving research data.

Their conclusions, described in a report* this week (see Editorial, p. 368), boil down to three "principles" that are as uncontroversial as motherhood and apple pie: Researchers are responsible for ensuring the integrity of their data; data from published papers should be publicly accessible; and data should be properly archived.

The report also offers 11 recommendations urging scientists, institutions, journals, and other players to develop standards and provide proper training. The suggestions include a few new points—for example, data-sharing should include not just the raw data but also the computer programs used to analyze it. But there are no detailed guidelines.

The problem was that every time a panelist made a detailed proposal, another member would say it would not work in their field, says co-chair Phillip Sharp, a molecular biologist at the Massachusetts Institute of Technology (MIT) in Cambridge. So the committee couldn't be too specific, Sharp says. For example, says co-chair and emeritus MIT physicist Daniel Kleppner, astrophysicists don't really have issues with image manipulation because they work with public data sets, and if someone doctors an image, colleagues "can go right back and look" and catch it.

Journal editors seem a bit disappointed. The National Institutes of Health's Kenneth Yamada, an editor of *The Journal of Cell Biology*, which has worked out ways to screen for manipulated images that other journals have followed, calls the report's principles "an excellent foundation on which fields can build." But he suggests a "Phase Two" academies study focusing on digital imaging in biology. Katrina Kelner, managing editor, research journals at *Science*, who calls the report "welcome" and the principles "useful," expects journals themselves may have to work out the specifics. **–JOCELYN KAISER**

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*Ensuring the Integrity, Accessibility, and Stewardship of Research Data in the Digital Age, The National Academies Press

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