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Foreword

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Plant phenomics: from gene to form and function

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Abstract. To exploit the wealth of gene sequence information provided by the 'genomics revolution' and mine agricultural germplasm for genetic diversity, high resolution, high throughput technologies in plant physiology are required for bridging the gap between genotype and phenotype. This special issue is dedicated to plant phenomics approaches to provide the quantitative phenotyping needed to elucidate the genetic bases for agricultural traits, and to screen germplasm for genetic variation in form, function and performance. These new techniques will enable the discovery of mechanisms and adaptations of plant responses to the environment.

Additional keywords: abiotic stress, *Arabidopsis*, biotic stress, *Brachypodium*, chlorophyll fluorescence, crop yield, infrared thermography, maize, spectral reflectance.

Over the past decade, the 'genomics revolution' has radically changed plant biology. Sequencing of the genome of the model plant *Arabidopsis* represented a landmark in plant genomics and subsequently the genomes of many economically important crop varieties have been sequenced and annotated, including rice and maize. Plant genome sequences of model systems and non-crop species are also regularly appearing in international databases. We are now entering another new era in genomics where high throughput sequencing technologies will make re-sequencing of genomes to examine allelic variation affordable and fast, and gene expression analysis by cDNA sequencing will render microarray technologies obsolete. We will be presented with terabytes of sequence information, both from genomic and transcriptional origin, which will need to be given functional meaning. However, it is becoming apparent that even the existing plethora of genetic information has not been adequately exploited to further the goal of linking the blueprint of life to plant function and performance. A significant proportion of even the *Arabidopsis* genome is annotated as 'gene of unknown function' or annotated using only loose sequence homology based clues. Reverse genetic approaches to disrupt gene function often result in the unsatisfactory conclusion 'no visible phenotype'. The new bottleneck in this field has become high throughput physiology and phenotyping or in '-omics' terminology, 'plant phenomics'. This bottleneck is also apparent at the output end of plant biology, crop breeding. Marker assisted selection of high-yielding crop genotypes adapted to stressful environments is hampered by slow, often subjective manual phenotyping, requiring laborious destructive harvesting across many field environments and seasons. Non-destructive, high throughput crop evaluation in controlled environments and the field are sorely lacking in our breeding systems.

The need to correlate gene function, plant performance and environmental response, with high resolution and speed has never been so pressing. The world is facing several major challenges, which plant biology must meet. We are now experiencing a major crisis in food supply that will require at least a doubling of cereal grain yields before 2050, despite a disturbing stagnation in annual yield progress by traditional breeding technologies (see Furbank *et al*. 2009; and references therein). Exacerbating this problem is the impact of climate change on world agriculture and pressure to develop appropriate biofuel feedstocks that do not compete for prime agricultural land. Screening food crop and biofuel genotypes rapidly for genetic variation in yield and tolerance to abiotic and biotic stresses is required to meet this challenge and application of our knowledge of gene function to marker-assisted selection of new varieties coupled with recombinant DNA technology will require a rapid evolution of our plant phenomics tools.

There has been a global response to the need to develop plant phenomics approaches and infrastructure. In Australia we have seen creation of the $50M Australian Plant Phenomics Facility (www.plantphenomics.org.au) and similar efforts are underway worldwide, linked by an international network, the International Plant Phenomics Initiative (www.plantphenomics.com). In April this year, the High Resolution Plant Phenomics Centre, the Canberra node of the Australian Plant Phenomics Facility, hosted the First International Plant Phenomics Symposium. This meeting brought together researchers with the common goal of adapting their plant physiology tools to plant phenomics applications and applying these new technologies to their scientific questions. The papers contained in this special issue are drawn from the presentations given at this meeting and from other relevant research papers recently submitted to the Journal.

Technologies and scientific questions relevant to the global challenges outlined above are well represented in the contents of this special issue. Infrared thermography as a surrogate for measurements of transpiration and photosynthetic response to stress shows great promise in high throughput plant phenomics and can be used both in controlled environments (Qiu *et al.* 2009; Sirault *et al.* 2009) and in the field (Jones *et al*. 2009). The power of this approach is that it allows high throughput screening at the seedling level to be validated at the canopy level in a field environment, using the same genotypes and tools.

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A variety of spectroscopic techniques that elegantly delve into photosynthetic performance at the leaf and canopy level are also represented in this issue. These range from the leaf spectrometer used by Kiirats *et al*. (2009) to investigate feedback regulation of photosynthetic electron transport under stress to the large scale use of reflectance spectroscopy in crop, grasslands and forest canopies to determine photosynthetic efficiency, activity and biochemical pathway (Ač *et al*. 2009; Busch *et al*. 2009; Siebke and Ball 2009). Spectral reflectance and absorption measurements can potentially provide plant phenomics with a tool to non-invasively delve into plant function and chemical composition scalable from the tissue to the canopy level. At the leaf level, chlorophyll fluorescence has become a relatively affordable, commonly used research tool but it has only recently been combined with 2-D digital imaging of growth in phenotypic screening of whole plants for abiotic stress tolerance (Jansen *et al*. 2009) and in 3-D (using laser radar such as in Hosoi and Omasa 2009) for imaging the effects of herbicides on plants (Konishi *et al*. 2009). Badger *et al*. (2009) used chlorophyll fluorescence imaging to rapidly identify mutants in photorespiration (Badger *et al*. 2009), while Scholes and Rolfe (2009) illustrate the utility of this technique in following foliar disease symptoms and the potential for biotic stress tolerance screening. Screening of mutant populations such as those generated using the activation tagging technique (Ayliffe and Pryor 2009) for biotic stress tolerance has proven difficult and may benefit from application of such novel approaches.

Determining root function in soil and screening for optimising root structure and growth has long been a challenging field (see Gregory *et al*. 2009; and references therein). Access to water at depth for cereal species growing on stored soil moisture is of great importance for drought tolerance and screening of model species to elucidate genes responsible for root characters is underway. Recently developed small, short lifecycle crop models more appropriate to cereal species are excellent systems for phenomic screening (Watt *et al*. 2009). A variety of approaches ranging from imaging in thin layers of soil or artificial media to MRI and X-ray CT-scanning are represented in this issue (Faget *et al*. 2009; Gregory *et al*. 2009; Nagel *et al*. 2009; Yazdanbakhsh and Fisahn 2009).

The challenge for plant biology in responding to the global issue of elevating crop productivity in the face of climate change is to take gene discovery to the farm gate. Integrative plant biology requires us to scale from the gene to the biochemical process, to the leaf, the whole plant, to the canopy and crop. Plant phenomics offers the promise of an approach to help achieve this aim.

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