Meetings

Facing global change: the millennium challenge for plant scientists

41st New Phytologist Symposium 'Plant sciences for the future', Nancy, France, April 2018

Introduction

We entered the Anthropocene with the industrial revolution. This geological era is defined by the unprecedented impact of human activities on the planet's geochemical cycles, making us the main driving force of Earth environmental changes (Crutzen, 2002; Steffen *et al.*, 2011). Since the middle of the twentieth century the human population has tripled, reaching seven billion today and probably 10 billion by 2050 (United Nations, 2015). This dramatic increase, associated with the improvement in the welfare of the population, has led to the overexploitation of natural resources. Intensive agriculture and industrialization has resulted in global warming, modification of nutrient cycles, pollution and reduction of wilderness; and endangering the preservation of eco- and agro-systems (Tilman *et al.*, 2002; Steffen *et al.*, 2011; Ehrlich & Harte, 2015). Today, the challenge is not only to intensify agro-productions to feed, fuel and shelter the growing population; but to do so in spite of the consequences of climate change while lessening our impact on the supporting ecosystems (Godfray *et al.*, 2010; Ehrlich & Harte, 2015; Byrne *et al.*, 2018).

Plant sciences can play an important part in mitigating both the causes and consequences of the pressure population growth imposes on the environment. As the primary producer of eco- and agro-systems, plants are essential to assess and understand human-driven environmental changes (Loreau *et al.*, 2001; Lin *et al.*, 2008). They are also central tools to develop sustainable production methods (Godfray *et al.*, 2010; Ehrlich & Harte, 2015; Byrne *et al.*, 2018).

In this context, the 41st New Phytologist Symposium 'Plant sciences for the future' was set as an experimental interdisciplinary platform. Bringing together early career and leader scientists from different fields of plant sciences, it aimed to promote the development of transdisciplinary research projects to build a better understanding of the multiple aspects of the upcoming environmental challenges; and to produce robust solutions for society. A special debate chaired by Marc-André Selosse (Natural History Museum of Paris, France) and Richard Norby (Oak Ridge National Laboratory, TN, USA) highlighted the critical topics and knowledge gaps the scientific community needs to fill in order to harness plant sciences to solve these societal issues. This event, held in Nancy, France on 11–13 April 2018, hosted researchers from 70 universities, research institutes and companies representing 29 countries in the fields of Developmental biology, Evolutionary biology, Ecology, Plant–microorganism interactions, Physiology and Genetic engineering (Fig. 1). In this article we outline how all plant science fields contribute to understand the effects of global change and to developing innovative solutions to maintain agro-productions, promote sustainability and counteract climate change.

Exploring biogeochemical cycles

Human activities have altered global biogeochemical cycles. Colin Brownlee (Marine Biological Association, Plymouth, UK) illustrated the role of marine phytoplankton in the carbon (C) cycle, reminding that coccolithophores are responsible for much of the calcium carbonate formation on Earth. The increasing input of CO_2 into the atmosphere since the industrial revolution, which is responsible for ocean warming and acidification, is compromising the ability of coccolithophores to form calcium carbonate and therefore affecting the completion of the global C cycle (Orr *et al.*, 2005). Brownlee demonstrated the role of proton channels in the calcification process of calcite coccoliths. Elucidating the cellular mechanisms involved in biomineralization is essential to minimize human impact on these critical species.

Forests represents a major C sink (Pan *et al.*, 2011). Björn Lindahl (Swedish University of Agricultural Sciences, Uppsala, Sweden) highlighted the importance of plant–fungi interactions in nutrient cycling and soil fertility in boreal forests. Using high-throughput sequencing to elucidate boreal forest mycobiome and combining it with climatic, edaphic and forest productivity parameters, Lindahl's group showed that the composition of the fungal community is the principal driver of organic matter storage in those environments. Lindahl proposed that intensification of forest practices by changing soil fungal communities could improve the soil C stock in boreal forest but presents long-term soil fertility risks.

From the boreal forest to the steppe, Amy Austin (University of Buenos Aires, Argentina) demonstrated that photodegradation is a dominant force controlling C losses in semi-arid ecosystems (Austin & Vivanco, 2006). Recent findings of her team suggests that photodegradation of the leaf litter promotes its subsequent biotic degradation by increasing accessibility of labile C compounds to microbes (Austin *et al.*, 2016). Land-use or climate change altering vegetation cover could largely influence the effect of sunlight on C cycling in these ecosystems. Croplands are an anthropogenic biome that we could manage to increase potential C sequestration. Carbon dioxide reaction with minerals naturally moderates atmospheric CO_2 and this effect has been enhanced since the emergence of land plants (Berner, 1997). David Beerling (University of Sheffield, UK) proposed to exploit this natural phenomenon by adding fast-reacting silicate rocks on croplands to trap CO_2. Eventually, weathering products could run-off in to oceans and enhance alkalinity, counteracting acidification, and sustaining the growth of marine phytoplankton that we presented as crucial for the completion of C cycle earlier in this paragraph. Together, these results highlight the importance of expanding our knowledge about C and nutrient turnover on Earth to predict and actively minimize our impact on climate.

Assessing the effects of climate change on plant physiology

Global warming has increased the intensity and frequency of extreme climactic events. High amplitude of temperature variation is the major cause of important plant losses in eco- and agro-systems (Eiche, 1966; Boyer, 1982; Hatfield & Prueger, 2015).

Plant pre-adaptation to climate variations could limit losses (Wikberg & Ögren, 2007; Yordanov *et al.*, 2000). Drought acclimation of trees involves structural changes in wood formation and abscisic acid (ABA) is a key plant regulator of this acclimation (Gupta *et al.*, 2017). Andrea Polle (University of Göttingen, Germany) showed the importance of ABA signal perception and response in wood formation of drought-stressed trees. Cecilia Brunetti (CNR, Sesto Fiorentino, Italy) demonstrated how trees limit xylem conduits embolism by modulating their carbohydrate metabolism and how ABA is involved in restoring xylem transport ability.

Limiting water loss by modulating stomatal aperture is another plant survival response to drought. Predicting plant responses to different levels of drought is still difficult. Belinda Medlyn (University of Western Sydney, Australia) reviewed recent advances in 'optimal stomatal theory' and presented a new *in silico* model to understand and predict stomatal responses to drought and heat.

Environmental stresses such as changes in temperature can affect plant metabolism and growth (Sampaio *et al.*, 2016). Shuhua Yang (China Agricultural University, Beijing, China) showed that stomatal conductance and, in consequence, leaf photosynthesis and respiration are affected by cold stress via the regulation of the CBF-dependent cold signalling pathway in Arabidopsis (Zhou *et al.*, 2011). Owen Atkin (Australian National University, Canberra, Australia) suggested that, by boosting plant respiratory metabolism, global warming could increase CO_2 release and influence the future atmospheric CO_2 concentrations.

Understanding plant physiological and metabolic adaptive responses to climate change are key factors for the production of efficient prediction models. These models are necessary to improve or develop novel management methods of eco- and agro-systems that could limit plant losses in the future.

Maintaining plant productivity

In our demographic context, maintaining population welfare depends on our ability to intensify agro-production. Environmental changes are threats to the maintenance of crop yields in both agricultural and forests agro-systems. They have direct impacts on plant mortality and biomass (Lobell & Field, 2007; Schlenker & Roberts, 2009), and indirectly affect plant productivity by altering population dynamics of plant pests, symbiotic microorganisms and competitive species (Gregory *et al.*, 2009; Lindner *et al.*, 2010). Biotechnological or agronomic solutions are necessary to lessen the consequences of global change on plant production.

In this frame, understanding the genetic basis of wood production in different tree lineages may help to mitigate the repercussions of abiotic stress on forest productivity through adapted management plans. Andrew T. Groover (US Forest Service and University of California, Davis, CA, USA) reviewed the genetic basis of evolution of woody plants and highlighted species-specific or conserved gene modules regulating the development of dicot and monocot cambium (Zinkgraf *et al.*, 2017).

Environmental changes are modifying development and distribution of plant pests, threatening crop and forest productivity (Porter *et al.*, 1991; Logan *et al.*, 2003). Plant diseases are now responsible for *c.* 25% of crop losses (Martinelli *et al.*, 2015). Controlling their outbreak is crucial to maintain plant productivity. A strategy to contrast future pest spread is to engineer crops resistant to a wide variety of pathogens. Ralph Panstruga's team (University of Aachen, Germany) explores the role of the MILDEW RESISTANCE LOCUS O genes (Jørgensen, 1992) – encoding members of a family of membrane integral proteins conserved in plants – in conferring multiple resistances. They showed that mutations in MLO genes improved *Arabidopsis thaliana* resistance to several leaf epidermal cell penetrating pathogens, but increased susceptibility to microbes with different invasion strategies (Acevedo-Garcia *et al.*, 2017). Stella Cesari (INRA, France), 2017 Tansley Medal winner, proposed to exploit the complex mechanistic and structural variability of nucleotide-binding domain and leucine-rich repeat-containing proteins (NLRs) to increase sensitivity or extend specificity of pathogen effector recognition (Cesari, 2017).

Understanding plants adaptive strategies to global change

Plants are increasingly exposed to new environmental stresses such as habitat degradation, climate change and the expanding range of invasive species and pests (Anderson *et al.*, 2011). To predict the consequences of global change on ecosystems, it is necessary to understand the different levels of plant adaptation (phenotypic plasticity, dispersion capacity and evolution) to new threats.

Plants can modulate the phenotypic plasticity of their neighbours by emission of volatile organic compounds (VOCs). André Kessler (Cornell University, Ithaca, NY, USA) showed that VOCs emitted by *Solidago altissima* upon herbivore attack alter herbivore dispersal and feeding behaviour through the modification of the

Fig. 1 Group photograph of the attendees of the 41st New Phytologist Symposium 'Plant sciences for the future' in the entrance of the Hôtel de Ville, Nancy (France). Photograph by Steven White, Leeds Media Services.

metabolism of non-attacked plants. This indicates spreading the risk of herbivory to neighbours as a fitness-optimizing strategy. The high variability of VOC types and levels in the field suggests the possibility of herbivore-driven natural selection on chemical communication (Morrell & Kessler, 2017). This might modulate crop adaptability to newly introduced pests.

Linda F. Delph (Indiana University, Bloomington, IN, USA) reminded the audience that the phenotype is the direct interface between the organism and its environment and therefore at the centre of evolution. She showed that genetic selection on key fitness traits such as flower number and height was strongly influenced by the environmental conditions in *Silene latifolia*. In-depth investigation of environmental factors influencing plant evolution may help predict phenotypic traits and fitness of plants in changing ecosystems.

Flower development is one of the most intricate and finely tuned processes influencing plant reproductive success. The floral organ must acquire specialized structures, bloom at the right time of the year and bear coevolving traits with its pollinators. By taking advantage of the -omics technologies, several groups found that specific transcription factors (TFs) evolved to allow the formation of elaborate and diverse floral petals. Elena Kramer (Harvard University, Cambridge, MA, USA) presented the role of the AqJAGGED gene, a TF involved in multiple key aspects in *Aquilegia* flower morphogenesis (Min & Kramer, 2017), while Hongzhi Kong (Institute of Botany, Beijing, China) showed that NpLMI1 and NpYAB5-1 are involved in the control of *Nigella* petal shape.

Since the first observations of pollination systems by Darwin (1862), researchers have been seeking for evidence of pollinator-promoted selection for diverse floral shapes. Babu Ram Paudel (Yunnan University, China) showed how two alpine gingers (*Roscoea purpurea* and *R. tumjensis*) occur sympatrically and have similar morphology, but are reproductively isolated through a combination of phenological displacement of flowers and different attracted pollinators. Global change might reshape these evolutionary boundaries and modify population or speciation dynamics.

Human impacts on the environment will influence plant traits and drive their evolution by modulating plant fitness (resistance to pathogens, pollination, population dynamics). However, plant plasticity might provide a key for plant adaptability on the short term.

Innovative plant technology: a role for basic and applied science

Understanding the genetic and molecular basis of phenotypes is key to groundbreaking biotechnological applications; hence the importance of tight coordination and synergy between basic and applied sciences. The Symposium hosted researchers interested in fundamental biological mechanisms, scientists involved in both basic and applied research and developers employed in biotechnology companies, aiming to bridge their complementary mindsets.

Understanding the molecular aspects of nutrient uptake and storage by plants is crucial to improving the yield or nutritional properties of crops. By investigating the developmental biology of rooting systems in early land plants, Liam Dolan (University of Oxford, UK) showed that the development of rooting structures in land plants is tightly controlled by some conserved TF networks (Breuninger *et al.*, 2016; Proust *et al.*, 2016). Such highly conserved key regulators can be used to enhance crops ability to access nutrients (Dolan *et al.*, 2011; US Patent Application no. 12/451,574). The fine-tuning of lateral root emergence is another central aspect of root systems development. Keith Lindsey (Durham University, UK) showed how the 36-aa peptide POLARIS, orchestrating the auxin–ethylene crosstalk, modulates lateral root emergence (Chilley *et al.*, 2006). These signalling mechanisms affect plants' access to water and nutrients and mediate plant plasticity in a changing environment. The regulation of the level of reserves is also fundamental to plant nutrition. Alison M. Smith (John Innes Centre, Norwich, UK) highlighted the importance of clock genes, which modulate starch production and degradation for efficient plant sustainment (Graf *et al.*, 2010; Scialdone *et al.*, 2013). Arabidopsis leaves modulate the rate of starch degradation according to the duration of the night, in order not to starve before dawn (Fernandez *et al.*, 2017). A better understanding of the dynamics of plant nutrient reserves may help engineering stress-resistant or nutrient-rich crops.

Examples of basic sciences translated into innovative plant technologies were given at the symposium. As presented earlier, David Beerling is exploiting silica weathering to counter accumulation of excess atmospheric CO_2. These results involved integrative studies spanning through geology, chemistry, economy and plant sciences, demonstrating once more the inestimable power of transdisciplinary research. Anne Osbourn (John Innes Centre) showed that through coexpression, evolutionary co-occurrence and epigenomic coregulation genomes can be mined for biosynthetic gene clusters involved in production of secondary metabolites (Medema & Osbourn, 2016). Their genetic manipulation allows the production of specific chemicals at a lower cost than conventional synthetic chemistry (Owen *et al.*, 2017). Technical platforms and start-ups are being born in the exciting field of plant chemistry (Reed *et al.*, 2017).

In conclusion, the symposium highlighted the need of integrative research to (1) understand, model, predict the consequences of global change on ecosystems and plant physiology, productivity, epidemiology; (2) create innovative solutions to future challenges in the fields of food security, sustainable crop management and efficient production; (3) diffuse knowledge and know-how among specialists and the general public. To this purpose, the symposium was closed by a public talk on plant–microorganism interactions, given by Marc-André Selosse with the beautiful background of the Hôtel de Ville of Nancy.

Acknowledgements

The authors thank the New Phytologist Trust and the Lab of Excellence ARBRE for organizing this symposium. The authors are grateful to all attendees who contributed to the stimulating atmosphere of this conference. A special acknowledgement to M-A. Selosse and R. Norby for leading the debate on the role of plant sciences in solving societal issues. The authors thank A. Austin, A. Polle, B. Medlyn, L. Wingate and A. Kessler for their time and advice during the mentoring session on Gender equality in plant sciences. The authors are grateful to F. Martin and the New Phytologist Trust for their support and helpful comments on the report. This work was supported by the LabEx ARBRE (ANR-11-LABX-0002-01), the Région Grand-Est, the University of Lorraine, the Genomic Science Programme of the US Department of Energy as part of the Plant–Microbe Interfaces Scientific Focus Area and, the ANPCyT (PICT 2015-1231, PICT 2016-1780), the University of Buenos Aires (UBACyT) and the CONICET of Argentina.

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Key words: biochemical cycles, climate change, food security, holobiont, phenotypic plasticity, plant adaptive strategies, plant productivity, plant sciences.