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eXtra Botany

Special Issue Editorial

Plant phenotyping for a sustainable future

Several complex and interconnected megatrends such as climate change, environmental degradation, and stagnating yields threaten crop production and world food security for a growing global population (Maggio *et al.*, 2018). This poses the challenge to develop sustainable and resilient agroecosystems with increased productivity as a key objective for the coming decades. In the past, agriculture has expanded production by breeding as well as by increasing inputs and farming areas. However, the projected scenarios call for considerable reductions in agricultural inputs such as water, fertilizers, and agrochemicals to reduce their environmental burden, whilst also addressing the decreasing land availability in many European countries. Integrated solutions and new technologies to improve plant production, based on knowledge-driven innovations in the farming sector and in agricultural and seed industries, have become the key objectives on the way towards sustainable agriculture (da Silva, 2015; Watt *et al.*, 2020; Morisse *et al.*, 2022).

On average, and across all major arable crops cultivated in Europe, progress in breeding has contributed about 80% to overall productivity growth, based on genomic selection on yield but also, increasingly, on phenotypic traits that bring adaptations to environmental conditions, and that contribute to environmental and socio-economic benefits (Noleppa and Cartsburg, 2021). While genotyping efficiency is becoming increasingly rapid and its costs are declining, the extensive and growing genetic information obtained must be matched with quantitative analysis of crop performance with respect to structure, function, quality, and interaction within the environment; i.e. plant phenotyping. This has been recognised as being key in crop improvement and has been undergoing increasingly rapid development within the last decade, boosted mostly by new capabilities in process such as imaging and image analysis, automation, computing, and data analysis. This progress in phenotyping can be seen in the large increase in the number of publications from around 2010, with plant phenotyping increasingly being used to address a multitude of questions (Costa *et al.*, 2019). Plant phenotyping has made substantial progress but still faces challenges that are inherent in the complexity and diversity of plants and traits, and the countless environmental scenarios that need to be quantified (Box 1).

Technological progress in hardware and software solutions has contributed to the advancement of plant phenotyping facilities and tools by increasing the use and application of non- or minimally invasive technology in automated modes that allows high-throughput assessment of a diversity of traits. Efforts have also been made in the development of affordable tools and approaches to meet the diverse needs of the research community, making plant phenotyping more accessible (Araus and Kefauver, 2018; Reynolds *et al.*, 2019). It is important to remember that phenotyping is a rather complex tool and there is no one-size-fits-all solution. There is a large diversity of requirements to measure physiological and structural plant traits both above and below ground, from the level of tissues to plant to canopy, and from processes that occur over seconds in photosynthetic energy conversion to long-term processes such as growth and biomass accumulation—and all this in a dynamic biotic and abiotic environment. Hence, plant phenotyping will need to be continuously developed and adapted in order to address emerging questions, to deepen our knowledge of plant processes, and to help us to advance towards sustainable and resilient agriculture. Integrated concepts, technical solutions, and multi-scale methods and approaches are needed to fully exploit its potential. This cannot be effectively addressed at the institutional level or even within a single country. Therefore, integration of plant phenotyping efforts at national or regional levels is needed to enable plant scientists to better understand plant performance and to translate our knowledge into applications (see Pieruschka and Schurr, 2022).

The International Plant Phenotyping Symposia initiated by the International Plant Phenotyping Network (IPPN; https://www.plant-phenotyping.org/) has been bringing the global plant phenotyping community together to exchange information and ideas, complemented by publication of the latest research in dedicated special issues in different journals (Pieruschka and Poorter, 2012; Pieruschka and Lawson, 2015; Reynolds and Schurr, 2019; Pommier *et al.*, 2020). This current special issue continues the successful series of publications and has been stimulated by the Society of Experimental Biology

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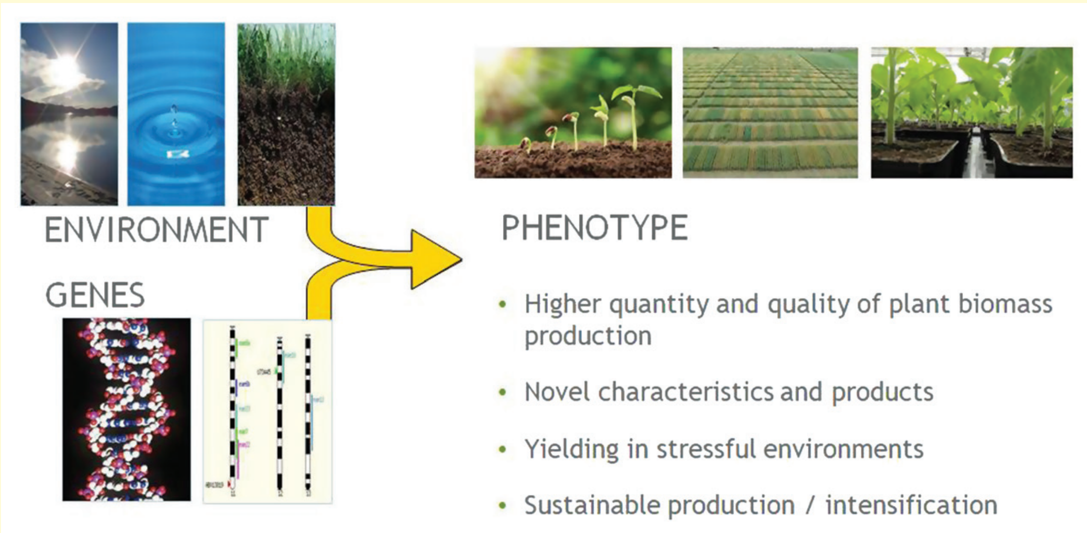
BOX 1. Plant—environment interaction

The functional body of the plant (‘Phenotype’) is formed during growth and development from the dynamic interactions between the genetic makeup (‘Genes’) and the physical world in which the plant develops (‘Environment’). These interactions determine plant performance and productivity, as measured by accumulated biomass and commercial yield, resource-use efficiency, and sustainability of plant production. Plant phenotyping is the process of quantitatively characterizing the structural and functional properties or traits of a phenotype within a dynamic environment. It represents an approach to delivering an integrated understanding of plant–environment interactions that can be translated into practical applications such as breeding or agronomy.



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virtual conference (SEB2021) and numerous activities initiated during the COVID-19 pandemic by the IPPN, the EU project EPPN^{2020}, and by the plant phenotyping research infrastructure project EMPHASIS (https://emphasis.plant-phenotyping.eu/).

Current developments in plant phenotyping

This special issue addresses plant phenotyping as the key tool for understanding plant–environment interactions across different scales of resolution, from cellular to the whole plant (Janni *et al.*, 2019). The reviews and research papers presented here highlight the ability of plant phenotyping to increase our understanding of plant performance and crop productivity and to improve it in terms of quality and tolerance to biotic and abiotic stresses. Climate change and the growing demand for food for both human and animal consumption during recent decades require ongoing development of climate-smart and resilient crops. Two review articles in this special issue present examples of how plant phenotyping can contribute to agricultural improvement. The Pannonian Plain has traditionally been a highly productive agricultural region in south-east Europe, with a high level of plant breeding and research playing an important role. Further advancement and implementation of phenotyping capacities will help us to explore the full potential of this region and further increase the agricultural productivity there (Kondic-Spika *et al.*, 2022). The Nordic countries represent another region with very specific challenges with regards to crop cultivation, particularly because of the short growing season, long days, and the need for frost tolerance (Roitsch *et al.*, 2022). Both regions are increasingly affected by climate change and there is a need for the development of adaptive capacity of crops that are both more climate resilient and perform well. Hence, regional strategies to implement phenotyping capacities in a coordinated way have been identified as being essential to effectively address the challenges and to utilize limited resources.

Environmental stress can be diverse and affect plant productivity in different ways, and three reviews address different aspects of stress effects on plants. Pettenuzzo *et al.* (2022) describe the importance of understanding thermotolerance mechanisms in viticulture, and evaluate key traits with the aim of improving field management strategies and developing more resilient varieties. Waterlogging results in a different set of molecular and physiological responses, and presents an important challenge for plant phenotyping in Nordic countries

(Langan *et al.*, 2022). Profiling of the activities of key enzymes is emerging as a valuable tool to integrate cell physiological phenotyping into a functional phenomics approach to assess stress responses (Jammer *et al.*, 2022). There is growing interest in the use of biostimulants as a tool for sustainable green economics in the agricultural context and how phenotyping can serve to identify new compounds and assess their biological activities and their mechanisms/modes of action (De Diego and Spìchal, 2022).

Dedicated research papers complement these reviews by showcasing specific examples related to abiotic stress, including the resilience of wheat to high temperatures and drought (Correia *et al.*, 2022), the responses of tomato to salinity, waterlogging, and elevated CO_2 under controlled conditions (Zhou *et al.*, 2022), the responses of rapeseed to waterlogging under field conditions (Li *et al.*, 2022), the water-use efficiency of rice (Affortit *et al.*, 2022), the combined nitrogen and water contents of lettuce (Weksler *et al.*, 2022), the biotic interactions with root-associated microorganisms that stimulate growth and nutrient uptake in *Brachypodium* (Kuang *et al.*, 2022), and the prediction of strawberry powdery mildew disease using spectral analysis of canopy reflectance combined with genomic information (Tapia *et al.*, 2022).

Plant phenotyping also provides data for the development of models. Aphalo and Sadras (2022) introduce a conceptual model linking developmental and evolutionary ecology with the acquisition of information through sensing of cues and signals that shows a multivariate complexity of the phenomics space and provides an explanation of pre-emptive acclimation. Additional models are also needed to improve the predictability of yield, and this issue is explored by Sarzaeim *et al.* (2022) in the use of climate data in crops such as maize.

Overall, the range of contributions that form the core of this special issue show that plant phenotyping is becoming an increasingly important tool for many basic and applied questions in plant science, and integration of efforts is essential for further progress.

Future perspectives

Plant phenotyping has become an essential tool in disciplines such as breeding and precision farming, both under controlled conditions as well as in the field. Phenotyping can exploit advances in non-invasive sensor technology, machine learning, and robotics to improve efficiency, accuracy, and resolution. Further advancement of phenotyping towards sustainable plant production requires the integration of different elements. Phenotyping tools and technology have to be further developed and include environmental observations of diverse crops and traits of interests within dedicated facilities. Despite growing capacities and increasing throughput, plant phenotyping will never be able to measure all the plant–environment interactions experimentally, and hence harmonization is needed from experimental design to data acquisition and the reusability of data in models (Saint Cast *et al.*, 2022). This will help us to identify the largest gaps *in vitro* and to address them experimentally in a targeted way, which will advance our knowledge of plant–environment interactions and hence contribute to improving our understanding of multiscale systems such as climate change, the transition of agriculture towards agroecology, and associated bioeconomic developments.

Plant phenotyping has become a very cross-disciplinary research field, connecting the expertise of engineers, computer vision scientists, data scientists, plant scientists, and geneticists. An integration of effort is needed towards joint development and implementation of new hardware and software programs as well as data management and modeling capacities in order to be able to address the diversity of parameters such as crops, traits, and environmental conditions. Given the range of facilities, tools, and methods available, a coordinated approach is needed to effectively utilize limited resources. In particular, an integration of effort between scientists, organizations, and countries is needed to effectively address urgent questions related to sustainable agriculture. This will minimize duplication of efforts, and a coordinated approach will lead to a focus on the tools that are most needed and that will have the largest impact. An example of such an approach to integrate the community is the research infrastructure EMPHASIS, which aims at building a legal and scientific basis to coordinate and jointly advance the plant phenotyping and plant science community in Europe and beyond.

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References

Affortit P, Effa-Effa B, Sokhatil Ndoye M, *et al*. 2022. Physiological and genetic control of transpiration efficiency in African rice, *Oryza glaberrima* Steud. Journal of Experimental Botany **73**, 5279–5293.

Aphalo PJ, Sadras VO. 2022. Explaining preemptive acclimation by linking information to plant phenotype. Journal of Experimental Botany **73**, 5213–5234.

Araus JL, Kefauver SC. 2018. Breeding to adapt agriculture to climate change: affordable phenotyping solutions. Current Opinion in Plant Biology **45**, 237–247.

Correia PMP, Westergaard JC, Bernardes da Silva A, da Silva AB, Roitsch T, Carmo-Silva E, Marques da Silva J. 2022. Functional high-throughput phenotyping for wheat resilience to high temperature and drought stress. Journal of Experimental Botany **73**, 5235–5251.

Costa C, Schurr U, Loreto F, *et al*. 2019. Plant phenotyping research trends, a science mapping approach. Frontiers in Plant Science **9**, 1933.

da Silva Dias JC. 2015. Plant breeding for harmony between modern agriculture production and the environment. Agricultural Sciences **6**, 87–116.

De Diego N, Spichal L. 2022. Plant phenotyping approaches in biostimulant research and development. Journal of Experimental Botany **73**, 5199–5212.

Jammer A, Akhtar SS, Buchvald Amby D, Pandey C, Mekureyaw MF, Bak F, Roth PM, Roitsch T. 2022. Enzyme activity profiling as an emerging tool for cell physiological phenotyping within functional phenomics to assess plant growth and stress responses. Journal of Experimental Botany **73**, 5170–5198.

Janni M, Coppede N, Bettelli M, *et al*. 2019. In vivo phenotyping for the early detection of drought stress in tomato. Plant Phenomics **2019**, 6168209.

Kondic-Spika A, Micic S, Mirosavljevic M, *et al*. 2022. Crop breeding for changing climate in Pannonian region towards integration of modern phenotyping tools. Journal of Experimental Botany **73**, 5089–5110.

Kuang W, Sanow S, Kelm JM, Mueller-Linow M, Andeer P, Kohlheyer D, Northen TR, Vogel JP, Watt M, Arsova B. 2022. N-dependant dynamics of root growth and nitrate and ammonium uptake are altered by bacteria *Herbaspirillum seropedicae* in cereal model *Brachypodium distachyon*. Journal of Experimental Botany **73**, 5306–5321.

Li J, Xie T, Chen Y, *et al*. 2022. High-throughput UAV-based phenotyping provides insights into the dynamic process and genetic basis of rapeseed waterlogging response in the field. Journal of Experimental Botany **73**, 5264–5278.

Langan P, Villo B, Walsh J, Bernád V, Walsh J, Henchy J, Khodaeiaminjan M, Mangina E, Negrão S. 2022. Phenotyping for waterlogging tolerance: current trends and future prospects. Journal of Experimental Botany **73**, 5149–5169.

Maggio A, Scapolo F, van Criekinge T, Serraj R. 2018. Global drivers and megatrends in agri-food systems. In: Serraj R, Pingali P. eds. Agriculture & food systems to 2050. global trends, challenges and opportunities. World Scientific Publishing, Singapore, 47–83

Morisse M, Wells DM, Millet EJ, *et al*. 2022. A European perspective on opportunities and demands for field-based crop phenotyping. Field Crops Research **276**, 108371.

Noleppa S, Cartsburf M. 2021. The socio-economic and environmental values of plant breeding in the EU and for selected EU member states. HFFA Research Paper 2021. https://hffa-research.com/wp-content/uploads/2021/05/HFFA-Research-The-socio-economic-and-environmental-values-of-plant-breeding-in-the-EU.pdf.

Pettenuzzo S, Cappellin L, Grando MS, Costantini L. 2022. Phenotyping methods to assess heat stress resilience in grapevine. Journal of Experimental Botany **73**, 5128–5148.

Pieruschka R, Lawson T. 2015. Preface. Special issue: phenotyping in plants. Journal of Experimental Botany **66**, 5385–5387.

Pieruschka R, Poorter H. 2012. Phenotyping plants: genes, phenes and machines. Functional Plant Biology **39**, 813–820.

Pieruschka R, Schurr U. 2022. Origins and drivers of crop phenotyping. In: Walter A, ed. Advances in plant phenotyping for more sustainable crop production. Burleigh Dodds Science Publishing Limited, Cambridge, UK, 1–25.

Pommier CG, Lawrence-Dill CJ, Pridmore T, *et al*. 2020. Editorial: phenotyping; from plant, to data, to impact and highlights of the International Plant Phenotyping Symposium – IPPS 2018. Frontiers in Plant Science **11**, 618342.

Reynolds D, Baret F, Welcker C, *et al*. 2019. What is cost-efficient phenotyping? Optimizing costs for different scenarios. Plant Science **282**, 14–22.

Reynolds M**,** Schurr U. eds. 2019. The 4th International Plant Phenotyping Symposium. Plant Science **282**, 1–104.

Roitsch T, Himmanen KI, Chavade A, Jaakola L, Nehe A, Alexandersson E. 2022. Functional phenomics to improve crop resilience in Nordic agriculture within climate change scenarios. Journal of Experimental Botany **73**, 5111–5127.

Saint Cast C, Lobet G, Cabrera-Bosquet L, Couvreur V, Pradal P, Tardieu F, Draye X. 2022. Connecting plant phenotyping and modelling communities: lessons from science mapping and operational perspectives. in silico Plants **4**, diac005.

Sarzaeim P, Munoz-Arriola F, JarquÌn D. 2022. Climate and genetic data enhancement using deep learning analytics to improve maize yield predictability. Journal of Experimental Botany **73**, 5336–5354.

Tapia R, Abd-Elrahman A, Osorio LF, Lee S, Whitaker VM. 2022. Combining canopy reflectance spectrometry and genome-wide prediction to increase response to selection for powdery mildew resistance in cultivated strawberry. Journal of Experimental Botany **73**, 5322–5335.

Watt M, Fiorani F, Usadel B, Rascher U, Muller O, Schurr U. 2020. Phenotyping: new windows into the plant for breeders. Annual Review of Plant Biology **71**, 689–712.

Weksler S, Rozenstein O, Ben Dor E. 2022. Continuous seasonal monitoring of nitrogen and water content in lettuce using a dual phenomics system. Journal of Experimental Botany **73**, 5294–5305.

Zhou R, Yu X, Song X, Rosenqvist E, Wan H, Ottosen C-O. 2022. Salinity, waterlogging and elevated [CO_2] induced interactive and complicated responses in cultivated and wild tomato. Journal of Experimental Botany **73**, 5252–5263.

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