Plant Science Research Network
Plantae.org/PSRN

The Plant Science Decadal Vision (2020 - 2030): Reimagining the Potential of Plants for a Healthy Future

EXECUTIVE SUMMARY

Impetus Behind the Decadal Vision

Plant systems and knowledge about them are key to the future health of the planet and its inhabitants. Addressing the large-scale and complex challenges we face, including the evolving role of humans in an increasingly automated world, requires bold, innovative changes to research cultures, training paradigms and strenuous efforts to broaden participation from the communities impacted by our work. The Decadal Vision therefore frames societally vital, exciting and far-reaching research challenges as being necessary and deeply interwoven with human and technical resources.

Behind the Decadal Vision is the Plant Science Research Network (PSRN), comprised of 15 scientific and professional organizations. The PSRN was formed to overcome ingrained habits of individualizing disciplines and subdisciplines within them, with an eye toward broadening thinking and lowering barriers to effective interdisciplinary integration of ideas and approaches. The Decadal Vision culminates four years of community engagement that has already led to visionary reports on future scenarios, cyberinfrastructure and postgraduate training. The Plant Summit 2019 and the Decadal Vision represent a culmination of these prior activities.

Our viewpoint is that plant science - and the life sciences more generally - are at a crossroads. On one hand, astonishing scientific opportunities are driven by conceptual and technological advances, however public engagement and diversity are lagging, while funding paradigms have tended to leave less space for unanticipated discoveries that open new doors. Furthermore, we argue that the incentives needed to drive the next generation of discoveries and applications are at odds with current institutional paradigms, reinforcing disengagement and an unhealthy homogeneity of perspective. These challenges intersect with urgent societal and environmental needs created by climate change and a growing world population. Human impact reducing species biodiversity and water resources, pollution issues, and increasing food and resource demands can be better understood and addressed through investments and participation in the plant sciences.

VISION AND VALUES

Our overarching vision for plant science research over the next decade is “Reimagining the potential of plants for a healthy future.” Our vision connects transformative thinking and discoveries in plant systems to environmental and societal benefits. Achieving our vision will require that the entire research endeavor develop and share values that support (1) **integration** - connecting discoveries, methods and applications; (2) **diversity** - inclusion of diverse participants, perspectives and research approaches; (3) **collaboration** - working collegially and synergistically with mutual respect; and (4) **justice** - committing to environmental integrity, equitable policies and recognition of communities and history.

STRATEGIC PRIORITIES

The Decadal Vision’s recognition of the vital intersection of human and scientific elements demands an integrated implementation strategy incorporating: research, people, and technology.

- Integrate plant systems **Research** to drive discoveries and application
- Support **People** and their environment for success
- Develop new **Technology** for more powerful data collection and analysis for knowledge generation and decision making

Discoveries and applications result from the availability of both technology and interested people, along with the physical, administrative and cultural environments that support them. People's interest, in turn, is driven by their understanding of the relevance and excitement of participating in plant science.

RECOMMENDATIONS

Goal 1: Harness plants for planetary resilience through deep understanding of ecological diversity and evolutionary change

A detailed understanding of interactions among organisms and their environments is needed that will enable building and testing of models displaying ecological and evolutionary changes from deep time to the present and into the future, in both wild and managed landscapes. The impacts of developing "virtual biospheres" range from an improved capacity to enable, engineer, and sustain robust ecosystems and their dynamics in the face of global change, to the development of novel approaches for conservation and restoration, carbon capture, bioremediation, soil health and ecosystem sustainability. Achievement of this goal, which will draw heavily on characterization of both nature and living collections, will afford a rich opportunity for citizen science.

Goal 2: Advance technology for diversity-driven sustainable plant production systems

Humanity needs novel production systems with greater crop diversity, efficiency, and resilience, which at the same time improve ecosystem health. Both species- and tool-driven approaches are required, involving both common and orphan crops; *de novo* domestication, gene editing and advanced breeding; the introduction of complex physiological traits such as perenniality; and an understanding of how ecological improvement concepts such as polyculture and soil health are best incorporated into mainstream cropping systems. We must also take advantage of our emerging understanding of how phytobiomes impact crop production and harness the potential of data science and engineering breakthroughs.

Goal 3: Develop 21st-century applications of plant science to improve nutrition, health and well-being

Using our understanding of metabolomics, synthetic biology, targeted breeding, and ecology, there are countless new ways in which plants can be harnessed to enhance human existence. These opportunities include discovering and engineering, within plants and their associated biota, potential medicines and other useful molecules, as well as developing plant-based tools for health research and therapeutics. In addition, the signaling and chemical interactions among millions of largely unstudied plant and microbial species offer an unparalleled window into understanding environmental diversity.

Goal 4: Develop the "Transparent Plant" tool to discern mechanistic insights and solve both vexing and urgent problems

The mechanisms that connect plant genes to whole-plant phenotypes, and ultimately to ecosystem dynamics, remain poorly understood at a systems level. The Transparent Plant is a needed interactive query and prediction tool that can achieve this goal by integrating data that scales from the atomic level to tissues, organs and whole-plant phenotypes. In accessing and integrating such an immense spectrum of information types in a user-friendly manner, the Transparent Plant will eclipse a major barrier to understanding how plants grow, react, and survive. Implementing this tool will require new biological knowledge and computational methods. The Transparent Plant is a platform both to explore the unknown through simulations and to serve as an action-oriented knowledge base for rapid-response problem solving when the country is challenged by new invasive species, pathogens, or other natural phenomena.

Goal 5: Reimagine the workplace to nurture and support adaptive and diverse scientists

Fully realizing our vision for plant science requires research environments that are inclusive, equitable, and geared toward incentivizing, supporting and rewarding collaborative research. We recommend implementing mentoring systems in which career development is enhanced through flexible and modular professional development training. Rather than being limited by an overriding emphasis on research productivity and focus, scientists will be supported to develop an array of transferable and cultural skills. For the faculty experience we recommend a balanced review process that includes both individual accomplishments and collaborative achievements, specifically recognizing the far-reaching scientific insights the latter delivers. We also promote "virtualizing the workplace," recognizing that technology increasingly facilitates seamless, global collaboration and workforce diversity by delivering accessibility to specialized knowledge and equipment, for both research and training purposes as well as to decrease carbon footprints of travel.

Goal 6: Build capacity and interest to engage with plant science

"Plant blindness" is a lack of awareness of the role that plant systems play in the daily lives of all people, which has led to dwindling resources for plant science. Improving "plant awareness" is the antidote. To build plant awareness and stimulate effective engagement, robust training in science communication, including both speaking and listening skills needs to be ubiquitous among plant scientists. Digital resources are needed to convey the excitement and relevance of participating in plant science, to generate enthusiasm about what plant science can contribute to our earth and our society, and to stimulate the imagination of its limitless potential. Plant awareness should target everyone, from young learners (K-12) to policymakers and scientists across plant fields through diverse non-plant fields, creating societal momentum for support of plant science investment and participation.

Technological improvements will support increasingly broad, sophisticated and consequential participation of citizen scientists, K-12 students and lifelong learners. These individuals and groups will support plant scientists' efforts to database living collections, identify species in natural environments, reinforce outreach activities, expand efforts to establish urban gardens or farms, and provide technical training for communities to take part in experiments using ecology, molecular biology, and computational approaches to science. To realize these possibilities fully, new technologies must be democratized through education coupled with strong incentives for equitable distribution, reduced cost, and reliable interfaces. Such efforts could be reinforced dramatically through appropriate integration into formal curricula.

Goal 7: New tools to revolutionize research

Transformative technologies can dissolve today's insurmountable obstacles and drive standards for the depth and rigor of discovery-based knowledge. The plant sciences will rely not only on technologies developed by plant scientists themselves, but also upon productive alliances among external technology developers, engineers, and other life scientists - alliances that must be strengthened and rewarded to ensure adoption and democratization.

In keeping with the major research goals, prioritized emerging technologies include portable and static non-invasive imaging abilities as well as sensors that can be applied directly to plants for monitoring above- and below-ground metabolic and microbial activities. Visualization is needed at many scales and modalities, and implementation will rely on automated image recognition, and major advances in speed, sensitivity, resolution, and portability, all coupled with lower cost. In addition, advances in edge computing, 5G wireless networks, and machine learning optimized computing provides opportunities to bring computing resources to remote sites of data collection. The "portable lab" can be extended far beyond imaging: already DNA sequence analysis is smartphone accessible, and critical plant science analytical technologies including chemical and protein analysis, are ripe for miniaturization and field deployment.

Goal 8: Ensure and realize the potential of Big Data

The lure and facility of massive data generation and analysis must be balanced with oversight of dataset management and interoperability. Spotty, error-ridden or poorly annotated data and analytical methods can impede discovery, and a lack of attention to quality amplifies the risk of misleading researchers and the public. As such, data management in plant sciences must adhere to the FAIR principles to ensure data are findable, accessible, interoperable, and machine readable. Similarly, new analytical techniques such as machine learning, image informatics, natural language processing, and artificial intelligence assisted data integration, pattern identification, and decision making are required for analyzing large-scale, multimodal data. Machine-readable literature, continuous integration of data streams, and increasingly automated approaches to data annotation and analysis will enable scientists to rapidly make new discoveries and suggest novel experiments. Successfully deploying these advances will allow rapid data analytics, engage users through low-cost mobile devices, and allow users to learn from remote locations.

DECADAL VISION ACHIEVEMENTS WILL INFLUENCE SCIENCE AND SOCIETY

This bold and visionary initiative will both transform its immediate field, and ripple outwards societally and globally. Impacts will be made within the plant sciences and related disciplines, and more generally for society and the planet we inhabit, to achieve the goals for 2030.

Research: Priorities and recommendations included in this decadal vision will convey systems insights at multiple scales, new approaches to sustainable agricultural production, and new uses of existing and novel plant systems that promote nutrition, health and well-being. They will also contribute far deeper holistic understanding of biodiversity and ecosystem services, thus generating improved tools for preserving and employing the natural world. For example, improved understanding of nutrient and water cycling along with algal biology will lead to fewer inputs and reduced algal blooms. Implementing our recommendations will lead to the decreased environmental footprint for agriculture so urgently needed from all facets of society, coupled with an increasing capacity for carbon sequestration that only plants, and plant science can address.

People: People provide the foundation and motivation for discovery research and its applications. The future demands a diversity of practitioners that reflects the population diversity of the nation; broad involvement of citizenry, whether school-aged or beyond; training and mentoring to support consideration and preparation for a suite of career choices; and academic cultural changes that prioritize and reward teamwork, equity, diversity, and inclusion. Building "plant awareness" includes providing knowledge about, and encouragement of, plant science-related careers with the goal of increased impacts of plant science endeavors across society in agriculture, environmental stewardship and human health. New discoveries combined with new opportunities will result in a surge of entrepreneurship including people currently underrepresented, leading to positive economic returns, domestically and internationally.

Technology: We envision accelerating progress in low-cost, democratized and often miniaturized technologies. Handheld devices will promote data acquisition in remote environments with data types ranging from images and genotypes to small molecules or population compositions. Coupled with the use of drones, we can expect increasingly sophisticated knowledge of the composition and dynamics of natural and managed systems. The implications for data quantities, standardization, transmission and interpretation are staggering. Chip makers, 5G providers, geographers, physicists, nanotechnologists, statisticians and machine learning specialists will engage and collaborate with plant biologists, scientists in related and distant disciplines, and business sectors as never before.