Plant Science Decadal Vision 2020–2030

Reimagining the Potential of Plants for a Healthy and Sustainable Future

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Executive Summary

Impetus Behind the Decadal Vision

Plants, and the biological systems around them, are key to the future health of the planet and its inhabitants. Plant science—and the life sciences in general—is at a crossroads. On the one hand, plant science research and technology breakthroughs have enormous potential to address pressing global issues such as food insecurity, climate change, species extinction, degraded water resources, and increasing pollution. On the other hand, public engagement is lagging, and severe funding limitations often discourage risk-taking. Therefore, realizing the potential of discoveries will require an imaginative and robust combination of communication, investment, and training.

In this spirit, the *Plant Science Decadal Vision 2020–2030* describes a holistic vision for the next decade of plant science that blends recommendations for research, people, and technology. Going beyond discoveries and applications, we, the plant science community, must implement bold, innovative changes to research cultures and training paradigms in this era of automation, virtualization, and the looming shadow of climate change. This document frames our ability to perform vital and far-reaching research in plant science as deeply interwoven with how we integrate and value participants and emerging technologies. Our vision and hopes for the next decade are encapsulated in the phrase reimagining the potential of plants for a healthy and sustainable future.

Behind the 2020 Decadal Vision is the Plant Science Research Network (PSRN), composed of 15 scientific and professional organizations. The PSRN was assembled to develop an inclusive, common vision across the plant science research community to promote interdisciplinary integration of ideas and approaches. The Decadal Vision culminates four years of community engagement that has already led to reports on how different futures might shape science in 2035, how cyberinfrastructure must evolve, and how a new vision for postgraduate training could change science.[1] The 2019 Plant Summit[2] brought together a diverse coalition of plant scientists to outline and conceive the Decadal Vision.

The Decadal Vision recognizes the vital intersection of human and scientific elements and demands an integrated implementation of strategies for research (Goals 1–4), people (Goals 5 and 6), and technology (Goals 7 and 8). This report is intended to help inspire and guide the research community, scientific societies, federal funding agencies, private philanthropies, corporations, educators, entrepreneurs, and early career researchers over the next 10 years.

Recommendations

1 Harness Plants for Planetary Resilience

Planetary resilience, including the resilience of our food systems, is utterly dependent on plants, which have evolved to survive and thrive in virtually every environment, including some of the most extreme conditions on Earth. Unlocking the secrets of their success and putting that knowledge to use, in agriculture and other applications, will require a detailed understanding of interactions among plants and their associated biota. To set the stage, we must accelerate activities to describe, catalogue, classify, and map the diversity and evolutionary history of plant populations, communities, and ecosystems. These efforts will lead to the necessary deeper insight into the intricate web of interorganismal signaling that occurs among the millions of largely unstudied plants and their associated symbionts, from microorganisms to pollinators. Then, this multifaceted information will be used to build and test computational models that accurately reflect ecological

and evolutionary changes from deep time to the present, and from genes to ecosystems, to predict organismal and ecosystem behaviors under novel conditions. These models will have a dramatic societal impact by informing decisions for developing species conservation strategies, sustaining ecosystem services, and improving agricultural systems and environmental health. Achieving this goal by drawing heavily on natural history and living collections will afford a rich opportunity for public engagement through community science.

2 Advance Technology for Diversity-Driven Sustainable Plant Production Systems

As needs for food, feed, and fiber continue to increase, we must be able to meet these demands in a manner that is both productive and sustainable.[3] Sustainability will be embodied in production systems that feature greater crop diversity, efficiency, productivity, and resilience while improving ecosystem health by integrating digital technologies into crop and livestock management. Priming this paradigm shift will be emerging tools in gene editing, synthetic biology, and advanced breeding used to target a broad array of consumer, producer, and sustainability traits. New knowledge will also underlie more effective incorporation of ecological concepts, such as biodiverse cropping systems (i.e., polycultures) and biosequestration (e.g., carbon capture), into agriculture. We must also take advantage of our emerging understanding of how phytobiomes—systems encompassing plants, their environments, and the microbes and other species they interact with—impact crop production and human health. Data science and engineering breakthroughs will be major drivers of this goal, allowing us to better predict, measure, and understand plant performance in the laboratory and field.

3 Develop 21st-Century Applications of Plant Science to Improve Nutrition, Health, and Well-Being

Many new tools applicable to plant production systems can also be harnessed to enhance human health through advances in nutrition and the discovery and engineering of plant-based medicines, including new classes of therapeutics. The effects on humans of interactions with plants must also be explored: what influences our responses—and those of our associated microbiomes—to plant-derived products? We point to additional potential for plant systems in non-agricultural functions such as bioremediation, urban farming, and many other managed landscapes.[4] To achieve the potential of these opportunities to improve human nutrition, health, and well-being, we need investment in rapid assessment tools, enhanced knowledge of the chemistry and physiology of plants and their associated biota, and research into how plant products interact with human genomes. We also need to increase public appreciation for how plants benefit humans and the environment from the landscape to the global scale.

4 Launch the Transparent Plant, an Interactive Tool to Discern Mechanisms and Solve Urgent and Vexing Problems

The Transparent Plant, an advanced computational tool, will deliver a full understanding of the inner workings of plants, breaking down the phytobiome into a "parts store" that supports tinkering and reveals the connections and signals that underpin plant characters. The ability to convert simulation rapidly into action would revolutionize how we think about and utilize plant systems. The Transpar-

ent Plant tool will be designed for both query and prediction. Its accuracy and utility will be derived through automated integration of massive new data sets that scale from the behavior of individual molecules to cells, organs, and ultimately whole plants. To develop a user-friendly and enterprising data warehouse will require a coordinated community data acquisition and utilization effort in this era of ever-expanding computational power. As it is progressively refined, Transparent Plant will be a platform that both enables exploration of the unknown through simulations and serves as an action-oriented knowledge base for rapid-response problem solving to address challenges presented by new invasive species, pathogens, and other natural phenomena.

5 Reimagine the Workplace to Nurture Adaptive and Diverse Scientists

Equity, diversity, and inclusion (EDI) are the cornerstones of greater participation and richer perspectives and thus are indispensable for fully realizing our vision for plant science. Although there is much to admire about the plant science research culture, it has resisted the major changes that we believe are needed. For example, some of the same incentives that will foster EDI will also incentivize, support, and reward collaborative and transdisciplinary research—the research of the future—in lieu of rewarding individual achievements. These incentives include direct funding and team mentoring for early career researchers, along with systems that support professional development through flexible and modular credentialed learning. This approach will balance emphasis on research productivity with development of pertinent transferable and cultural skills. In all organizational settings, a balanced system of professional rewards is recommended that recognizes and values both individual and undissected collaborative achievements. Open-source technologies can be used to support virtual workplaces and facilitate global collaboration.

6 Build Capacity and Interest to Engage with Plant Science

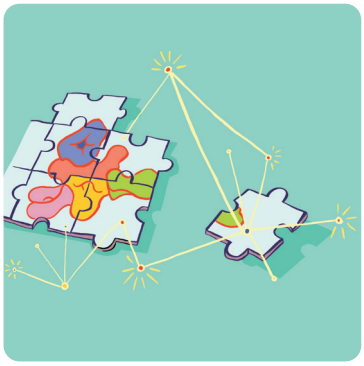
Plant life supports all life, yet people frequently take plants for granted. Plant awareness is an essential antidote that relies on effective engagement with the public by plant scientists and robust communication training in various forms. We must convey the excitement and relevance of participating in plant science to as many audiences as possible, and we need to stimulate imaginations with the limitless potential of plant science to address their needs. Using new technologies and media, community scientists—that is, students, citizen scientists, and lifelong learners who participate in research efforts—will increasingly contribute to databases of living collections, identify species in natural environments, and reinforce outreach activities. Technology development that enables virtual or distributed research must be coupled with incentives for equitable distribution and democratized access. Plant awareness activities should target everyone, from young learners to policy makers and scientists across the many disciplines that will contribute to our goals, creating societal momentum for support of plant science research.

7 Develop New Technologies to Revolutionize Research

Transformative technologies will overcome what today might appear to be insurmountable obstacles as they improve the depth and rigor of plant systems knowledge. Although plant scientists alone will develop some technologies, most technologies will arise and be perfected through alliances with technology developers, engineers, physicists, and other life scientists. Emerging technologies that best support our research

goals will focus on improving noninvasive imaging, such as above- and below-ground sensors for monitoring environmental, metabolic, and microbial activities, and on increasing the selection of plug-and-play portable lab technologies. Some devices will rely on automated image recognition that can be achieved only with major advances in speed, sensitivity, resolution, and portability, coupled with lower cost. In addition, advances in field-based (edge) and quantum computing, 5G and 6G wireless networks,[5,6] and data processing algorithms based on machine learning will help bring rapid computation to remote and rural sites for data collection and analysis by farmers, researchers, and community scientists.

8 Manage and Realize the Potential of Big Data

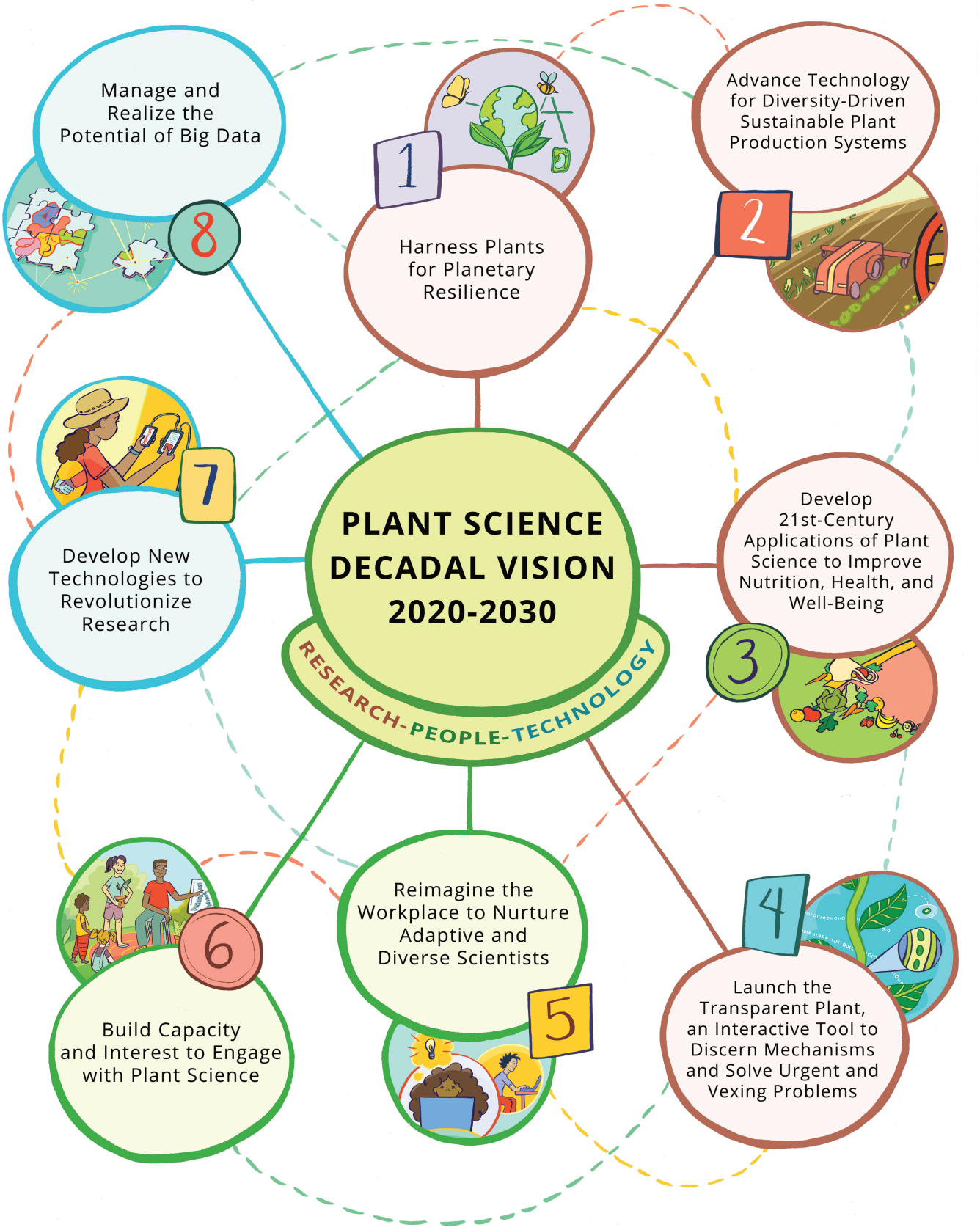


Growing capabilities for massive data generation and analysis must be balanced with oversight of data management and quality. Although the prevalence of spotty, error-ridden, or poorly annotated data and methods is sometimes overlooked, these weaknesses can have huge negative consequences. Data management in plant science must adhere to the FAIR principles[7]: ensuring that data are Findable, Accessible, Interoperable, and Reusable. This behind-the-scenes structure is essential if plant scientists are to piece together complex puzzles using ever-improving and increasingly automated techniques such as machine learning, natural language processing, and artificial intelligence–assisted data integration, pattern identification, and decision making.

Impacts on Society

Implementation of this bold Decadal Vision will transform the immediate field of plant systems science and ripple outward through society and across the globe. We will deepen our understanding of plants and their environments, advance agricultural sustainability, and develop entirely new uses of plant systems to promote nutrition, health, and well-being. The research goals will also lead to a far deeper holistic understanding of biodiversity and ecosystem services, generating improved knowledge for preserving the natural world and improving the human condition. Discoveries will result in a surge of entrepreneurship, leading to positive economic returns and other new opportunities. The spread of new technologies will only accelerate, increasing access to plant systems science and expanding research possibilities.

We view people as the foundation and motivation for discovery, research, and applications. Our recommendations therefore promote cultural changes that support the diversification and well-being of plant scientists and encourage community engagement. One mechanism to stimulate cultural change is the infusion of plant awareness across society, which is urgently needed in the era of climate change. Plant awareness efforts will play into people's natural curiosity about and desire to prepare for the future, leading them to seek fuller information about food, health, climate, and ecological systems and, in some cases, to join the scientific community.



The Plant Science Decadal Vision describes eight specific and interconnected goals in three areas: Research (red), People (green), and Technology (blue).