American Society of Plant Biologists

Cultivating a better future through plant biology research

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The goal of a sustainable future, with a more nimble and innovative workforce and a highly competitive research enterprise, is in the national interest. The challenge, however, is to execute this strategy in an era of economic limits, when anticipated outcomes must justify the investment of limited resources. Through an iterative, strategic visioning process, representatives of the plant science community developed the *Plant Science Decadal Vision* (http://bit.ly/197Eph9) that responds to the urgent needs and tremendous opportunities that confront our nation and the world. We cannot meet the food, feed, shelter, and energy demands of the burgeoning global population—especially with climate instability as a backdrop—while the American investment in plant-related research stagnates. Ending that stagnation, instead, can leverage the new technologies that have transformed biology, accelerating the pace of discovery and promising solutions that can be both creative and sustainable.

The initiative proposed here, which will dramatically increase the ability of plant scientists to understand, predict, and alter plant behavior, is synergistic with other national calls to action, including *A New Biology for the 21st Century*, the *National Bioeconomy Blueprint*, and the *Report to the President on Agricultural Preparedness and the Agricultural Research Enterprise*. Achieving the *Decadal Vision* will require cooperation among many stakeholders, including academia, federal agencies, the private sector, foundations, and international partners.

Failing to realize the promise for advances in plant science research will have sobering consequences. Chronic underinvestment leads to loss of competitiveness, missed opportunities, and environmental and community degradation through use of outmoded technologies. The 2012 *Report to the President on Transformation and Opportunity: The Future of the U.S. Research Enterprise* detailed this situation and argued for an investment in research and development (R&D) of 3% relative to gross domestic product. In the case of agriculture, in which current R&D investment languishes well below this number and other indicators are equally grim, an inability to deliver nutritious food and therapeutics could be catastrophic, ultimately posing a national security threat reminiscent of riots associated with recent commodity price spikes in the developing world.

The unique value of the *Decadal Vision* arises from its embodiment of a consensus agenda developed by international and domestic plant scientists, its linkage to other calls to action, its anticipated economic impact, and the clear and urgent need to reimagine how the research enterprise can and must support the agricultural sector.

Five interwoven components are recommended to accomplish the objectives:

1. Increase the ability to predict plant traits from plant genomes in diverse environments. Plant genetic blueprints underlie productivity, resistance to pests and diseases, and the ability to flourish in a wide array of environments and climatic conditions. However, the ability to interpret those blueprints, which reflect a complex evolutionary history, is only in its infancy. To bridge this knowledge gap, we recommend programs that will (1) link genome to performance during environmental change and biotic interactions by establishing the interconnections among a plant's genes, their myriad cellular products and functions, and the ways these determine agronomically important plant traits; (2) expand plant phenotyping capabilities, in particular drawing on advances in computation and robotics; (3) define how plant species have naturally adapted to stressful or extreme environments, specifying biological mechanisms that can be harnessed for agriculture; (4) understand the dynamics of plant communication, from the intracellular to the interorganismal scale; and (5) establish a comprehensive plant attribute database that integrates genetic, molecular, and chemical data with developmental, architectural, field performance, and environmental parameters.

2. Assemble plant traits in different ways to solve problems. Newly discovered traits will need to be introduced into crop species through 21st-century breeding strategies or the virtually unlimited possibilities of synthetic biology. To establish and implement these capabilities, we recommend (1) funding relevant research using challenge grants, collaboration strategies, and training programs that combine biology, breeding, engineering, and computational talent and (2) investing in large-scale genetic, genomic, and biochemical characterization of wild or heritage germplasm related to crop species.

3. Discover, catalog, and utilize plant-derived chemicals. One of Earth's greatest assets is its immense diversity of life forms, yet we have only scratched the surface in cataloging plant-derived chemicals and their biological purposes, even as species are lost through extinction. These uncharacterized chemicals constitute a virtually inexhaustible but mostly untapped resource for agricultural, bioproduct, and biomedical applications. To realize this potential, we recommend (1) determining the chemical composition and biosynthetic pathways in 20,000 ecologically and medicinally important species to understand the synthesis and biological purposes of plant-derived chemicals and (2) utilizing plant chemistry for applications in human health, agriculture, and manufacturing.

4. Enhance the ability to find answers in a torrent of data. For plant biology to become a reliably predictive science, data analysis must undergo a paradigm shift. De-fining the complex relationships that underlie plant behavior will require (1) integrating data through the perfection of statistical models, application of machine learning, and validation of functional predictions from models and (2) facilitating data storage, retrieval, and analysis through incentivizing, enabling, and training scientists to share data freely and habituating scientists to develop or test hypotheses through intensive data analysis before conducting wet lab or field experiments.

5. Create a T-training environment for plant science doctoral students. Innovation in agriculture will flourish only if training environments keep pace. The current doctoral training system, with its slow pace and focus on a traditional academic pathway with limited job prospects, is associated with dissatisfaction and attrition, stagnant trainee numbers, and stubbornly poor gender diversity at the faculty and executive levels. We propose implementation of a T-training format that retains the vertical, discovery-based scientific apprenticeship in a mentor's laboratory but adds horizontal skills that cross-train students and prepare them for a wide variety of careers while shortening the time to degree. To engage institutions, federally supported training grants would require suitable commitments from institutional and industrial partners.

Outcomes

Basic research has a tremendous track record of producing jobs, economic activity, and far-reaching societal benefits. Fundamental laboratory discoveries currently drive agricultural improvements in most major crops because the agricultural sector excels at implementing promising technologies. A recent example is submergence-tolerant rice; a gene identified through USDA-funded research has now been bred into multiple varieties grown worldwide. Likewise, the research proposed in the *Decadal Vision* can lead us to novel solutions for improving the sustainability of agriculture and the bioeconomy, even in the face of challenges such as climate change, population growth, and limited natural resources such as water and arable land.

A National Call to Action

The plant research community is not alone in recognizing the importance of 21st-century investments in plant and agricultural sciences and imperatively recommending substantial action to ensure the necessary infrastructure and human capital in research, education, and application. The specific recommendations for plant science defined here are synergistic with, and emergent from, several recent reports that highlight this watershed moment in plant science research.

A New Biology for the 21st Century is a 2009 National Academies study whose recommendations are meant to ensure that "the United States leads the coming biology revolution." One major recommendation of *New Biology* is that initiatives address societal challenges in food, energy, environment, and health. The *Decadal Vision* tackles each of these through the lens of interdisciplinary, plant-driven science. *New Biology* further assigns priority to information technologies, cross-disciplinary collaborations and curricula, and inter-agency collaborations, all of which are components of the *Decadal Vision*.

The *National Bioeconomy Blueprint* was published by the White House Office of Science and Technology Policy in April 2012. The blueprint extensively covers plant-based bioproducts and points to synthetic biology and bioinformatics as key modalities to achieve these goals. In the *Decadal Vision*, the emergence of new plant-inspired industries is envisioned in part through advances in these areas.

Finally, the President's Council of Advisors on Science and Technology (PCAST) *Report to the President on Agricultural Preparedness and the Agricultural Research Enterprise*, published in December 2012, concludes that the nation is not prepared for future agricultural challenges and recommends major R&D investments achieved through expanding the role of competition at USDA and increasing support through NSF.

Each of these three reports, like the *Plant Science Decadal Vision*, imparts a sense of urgency and arose from a collaborative process among research scientists, policymakers, and the private sector. Together they point unambiguously to both the threats and the opportunities that face the nation and illuminate a path forward.

To sustain crop productivity in an increasingly unstable climate, to deploy agricultural systems that protect natural resources, to use nature's biological and chemical innovations to solve problems that crops increasingly face (water, thermal, salinity, and nutritional stresses), and to capture the economic opportunities in improved crop varieties and novel plant bioproducts all require a visionary and interdisciplinary research capacity that is accompanied by coordination and openness in data sharing. These requirements entail not only an unwavering commitment to excellence and innovation by the research community, but also a serious commitment to reforming the existing model of graduate education. Each of these research and educational goals is addressed through one or more components of the *Plant Science Decadal Vision*.

The overarching objective of the *Decadal Vision* is to build across disciplines including plant science, chemistry, engineering, and computational sciences to advance research through the continuum of observational to predictive to synthetic. Among the possibilities within reach are improving the agronomic properties of crop varieties through, for example, rapid deployment of resistance to emerging pathogens; designing plants for new functions; using native plants as “libraries” to harness their adaptive mechanisms and novel products for medicine and industry; and understanding the roles and regulation of plant genes in thousands of species. To preserve and increase agricultural productivity in a wide range of environments will require a much deeper understanding of everything from photosynthesis, in which sunlight is initially captured, to the means by which plants perceive and communicate with many thousands of organisms that directly interact with them above and below ground. The exceptional ability of U.S. industry to implement technologies that have advanced through proof of concept is a further impetus to action.

Timely execution on the *Decadal Vision* is critical for many reasons. The goals being proposed are designed to protect and improve crop productivity, quality, and nutrition. They leverage conservation management activities that maintain and improve natural resources and precious, dwindling biodiversity, and they support the creation of new plant-inspired industries and “innovation ecosystems” directly in line with PCAST’s recommendations.

The objectives of the *Decadal Vision* are also aligned with international plant science priorities, which should facilitate the cooperation that will be required to understand the extreme complexity and diversity of plant life and to use the resultant insights. An international workshop held in 2009, for example, identified as high-level objectives resource conservation, data collection and sharing, and integration of information to understand plant function. International consensus on these research thrusts is perhaps not surprising given that the challenges facing agriculture are global.