Plant breeding for harmony between agriculture and the environment
White Paper
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Introduction

Developing sustainable societies is the grand challenge of the coming century. More food, feed, fiber, fuel, and forest products necessary to meet basic human needs must be produced from less land, water, and nutrients. A growing population will require expanded landscaping and urban forests to moderate the environment and produce suitable living spaces. Landscaping that requires less water, athletic fields that are durable and require less fertilizer, and parklands with restored native species will all contribute positively to human well-being.

Among the scientific disciplines essential to addressing this challenge, plant breeding will play a unique role by developing new crops, ornamentals, and forest trees that meet societal needs. Plant breeders will develop plants that are adapted to our changing environment and that can improve environmental quality.

Breeding to adapt plants to the environment

1. Producing more with less

As water becomes limiting and the cost of fertilizer and other agricultural inputs rise, continued gains in production per acre are essential to prevent natural habitat loss. By developing plants that use nutrients and water more efficiently, plant breeders will increase the sustainability of our agricultural, residential, and urban ecosystems. High yielding plants that require less fertilizer will not only decrease the cost of production but also reduce the amount of nitrogen and other nutrients that enter our water systems. Breeding plants that limit environmental problems stabilizes the economy while maintaining and improving quality of life.

2. *Adapting to global climate change*

Extreme weather events are expected to increase in both number and severity in coming years. One example is the flooding in the Midwestern USA in 2008, the second "500 year" event that has occurred within 15 years. To maintain productivity in the face of this variability, new plant cultivars and populations will need to be continually developed. Climate extremes will likely change the boundaries for growing particular species, cultivars, or populations. Field-based plant breeders will produce successful new cultivars adapted to this changing environment by adjusting their testing locations and their germplasm as these shifts occur. Preserving genetic diversity of important species is essential for breeders to be able to make these adaptations in the future. Genetic diversity from wild plant relatives will need to be rapidly incorporated into new cultivars if the climate changes quickly.

3. *Breeding for abiotic and biotic stress tolerance*

Improving environmental stress tolerance to maintain plant productivity under variable conditions is essential to all breeding programs. Plants that can tolerate extreme weather conditions, including drought, heat, and frost will be necessary. Even in the absence of climate change, other tolerances are necessary to maintain productivity. Tolerance to various soil conditions, most pressingly to acidic and aluminum-rich soils, will be increasingly important as land currently not regularly cropped is needed for production. Both in forestry and in agriculture, plant breeding can effectively and efficiently develop plants that tolerate both native and new exotic pests and diseases, thereby reducing the need for expensive and environmentally damaging pesticides. Breeding is sometimes the only means to ensure the continued planting of important species in the urban forest or to enable the species to survive in their native habitats. For example, current breeding programs are developing hardy elms and American chestnuts, species that are currently near extinction.

4. *Breeding for in-field diversity*

Planting two or more cultivars of different genetic background in the same field can help ensure that a crop is not devastated by catastrophic events, such as disease outbreaks or periodic drought. US farmers often plant several maize hybrids with different maturities to spread the risk of adverse weather during pollination. Plant breeders can develop multi-lines to increase crop diversity and ensure a wider coverage of environments and broader resistance to pathogens than is possible with a single uniform line. As climate variation increases due to global warming, the year-to-year and location-to-location variability may also increase, and under these circumstances, cultivars bred for in-field diversity will help farmers reduce risk of crop failure.

Breeding plants to improve the environment

Plant breeders can reduce the impact of agriculture on the environment without sacrificing productivity. In fact, addressing the current environmental concerns of modern agriculture by developing improved crops and cropping techniques will ensure that our high productivity is sustainable. New crop cultivars developed by plant breeders will help improve soil health, reduce soil erosion, prevent nutrient and chemical runoff, and maintain biodiversity. Making breeding choices based on the needs of the overall cropping system can present further opportunities to improve the environment.

1. Breeding for new uses

Plant breeders can tackle specific environmental problems by developing plants with new uses through classical plant breeding and, potentially, biotechnology. For instance, breeding can be used to develop plants that can remove toxic chemicals such as mercury or excess nutrients like N or P from the soil, or that can improve industrially degraded soils such as mine spoils. Biofuels can help mitigate global warming problems associated with fossil fuel use, and plant breeders can develop cultivars that have higher yield and

energy content. Public breeding programs have evaluated numerous potential energy crops and will lead the way in developing cultivars of these species for successful on-farm cultivation.

2. Breeding for local adaptation

Harmonizing agriculture with the environment means tailoring crops to individual landscapes. Plant breeding can target cultivars to specific local agricultural and managed recreational ecosystems by selecting plants based on their performance in the environment of interest, and involving everyone who will use the plant in the selection process. Participatory breeding on farms is one method to focus breeding efforts on specific traits, locations, and needs, involving both scientists and farmers.

3. Breeding for optimum cropping systems

Changes in cropping systems that make production more environmentally benign will require changes to selection methods. For example, no-tillage systems can lead to colder soils in spring that could change the prevalence and onset of a range of soil borne diseases. Breeders can select under conditions of the new system to ensure their cultivars will be optimally productive under the new management. Breeders can also develop cultivars for other alternative cropping systems that are even more distinct from current systems, such as intercropping two or more species growing in the same field at the same time.

4. Breeding alternative crops

Breeders working in new cropping systems and landscapes need to develop alternative crops, ornamentals, trees, and turfgrasses adapted to the new environments. Perennial crops can help prevent erosion in agricultural systems; drought tolerant grasses can provide low-input lawns in urban areas. These crops may not have been widely selected or domesticated previously but will need to be selected now. Cover crops are important components of organic and other agricultural systems to improve soil fertility and to control weeds and soil-borne diseases and pests. Many of the cultivars in use today are original selections from germplasm collections that have not have been specifically improved to increase their effectiveness and to eliminate negative traits, such as weediness. Because commercial breeding programs may not develop cultivars and populations with limited market potential, the public sector should breed these crops. Breeding alternative crops needs to be done in close consultation with agronomists, economists, and marketers, to ensure that the new crop can be profitably grown by the farmers.

Alternatives also exist for residential landscapes and forests. In particular, breeding of ornamentals, urban trees, and turfgrasses will increasingly look for alternative species that are better able to survive on less water, fewer nutrients, and with less herbicide or pesticide application and that are non-invasive. As new species are identified, breeding to

improve them for traits of consumer importance will undoubtedly need to be conducted, largely in the public sector in coordination with the private sector. Historically, the NRCS Plant Material Centers have a long history of breeding and selecting material for conservation and erosion control plantings and the US Forest Service has been breeding for resistance to exotic diseases.

5. Breeding for new agricultural paradigms

Based on scientifically sound findings in ecology and agronomy, scientists have proposed wholesale changes in our farming methods, such as the development and implementation of perennial polycultures that closely mimic natural ecosystems. Plant breeders have a major role to play in these systems, by domesticating, or re-domesticating, key species. Partial steps toward this vision could be achieved by improving individual crops that could fill gaps in our current system. Perennial wheat, for example, may ultimately be a component of a perennial polyculture, but in the context of current US wheat systems, it could serve to limit soil erosion when planted in strategic areas on the landscape. These breeding goals represent an opportunity for public sector scientists, taking a long view and developing prototypes that can then be adapted by commercial programs in the future.

6. Breeding for ecosystem services

In general, plants are bred for their most obvious end product, such as grain, fiber, sugar, or biomass yield, fruit quality, or flower color. However, plants deployed across the landscape in agricultural, horticultural, or forestry situations can also potentially impact the environment in various ways. Thus, while selecting for high yield, a breeder could also select for nutrient use efficiency that would improve water quality by reducing nutrient loading into ground and surface water. Likewise, simply selecting and breeding urban trees for pest and drought tolerance ensures that the ecosystem service benefits, such as stormwater management, evapotranspirational cooling, and mitigation of air quality, are maintained in urban areas. Increased productivity and disease resistance resulting from breeding programs have resulted in healthy and more productive ecosystems. Selecting for multi-functional plants that fulfill several goals simultaneously would result in systems with more benign environmental footprints than currently exist.

The necessity of public plant breeding

Achieving the disparate breeding goals described above must take a partnership between the public and private sector. The private sector excels at breeding major, profitable crops and has economies of scale to increase the efficiency of production. Public programs offer a valuable complement to commercial breeding programs, focusing on alternative crops, breeding for small target regions, tackling long-term and high risk problems, and importantly, conducting basic research on essential topics such as selection strategies and breeding methodology to enhance the efficiency of breeding programs.

Critically, only publicly funded breeding programs, and in particular those based at universities, can provide the necessary education to adequately train breeders in plant breeding theory and practice. Without public programs, no students will be trained, and commercial breeding programs will become less effective.

Ultimately, the public sector can take a broad long-term view by looking at the productivity of the overall agricultural system and at its positive and negative externalities. Breeding programs can then put resources toward ameliorating current environmental concerns. Selection for cover crops, for perennial crops, and for crops providing well rounded nutrition to humans and livestock will be significantly improved if the public sector gets involved in activities outside those being conducted by private industry.

The goals and roles of private and public institutions should be different, and when applied to plant breeding, should focus on different aspects of the big picture. Public scientists and agencies should focus their limited resources where it will do the most good—conducting excellent science to aid the development of stable and sustainable ecosystems, and in the process train plant breeders for commercial programs.

Opportunities for new partnerships

Diverse groups, many not traditionally associated with plant breeding or even agriculture, have much to gain by associating with and supporting plant breeding. Plant breeding is a powerful tool for meeting today's environmental challenges because it can develop plant products that simultaneously improve production and improve the environment. Further, the importance of plant breeding to environmental sustainability make it an attractive career opportunity for students and young scientists.

Groups not currently engaged with plant breeders may be interested increasing public and/or private support. Recently, farmers and farm groups associated with organic and sustainable agriculture movements have supported publicly funded breeding as a way to ensure they have seeds of a diversity of crops which are not controlled by agribusiness. These groups have been actively working to increase support for breeding in the public sector. Other groups, especially in the environmental arena, can probably be identified over time, with similarly positive results.

Deliverables

Support for public breeding will lead to three major deliverables: (1) improved germplasm and cultivars that will directly benefit producers and seedsmen, (2) scientific advancement leading to more efficient public, private, and NGO breeding programs, and (3) graduates that will be hired by industry, academia, the government, or other breeding programs. Both cultivar development and scientific research are essential if public programs are to adequately train new plant breeders, deliver improved germplasm and cultivars, and ensure that theses deliverables end up on increasing the all-around sustainability of the farms and nurseries that provide for our dinner plates and landscapes.

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