

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 the new crops, ornamentals, or 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 unit area to prevent natural habitat loss. By developing plants that use nutrients and water more efficiently, plant breeders will increase the sustainability of our agricultural, and residential, and urban ecosystems. For example, plants that produce higher yield with less fertilizer nitrogen will not only decrease the cost of production but also reduce the amount of nitrogen that enters 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. Field-based plant breeders adapt new plants to this changing environment. However, with increased climatic instability, quickly incorporating genetic diversity from wild plant relatives into new cultivars will be essential. Climate extremes will likely change the boundaries for growing particular species, cultivars, or populations. Breeders will adjust their testing locations and their germplasm as these shifts occur to produce successful

new cultivars. Preserving genetic diversity of important species is essential for breeders to be able to make these adaptations in the future.

3. *Breeding for abiotic and biotic stress tolerance*

Next to productivity, improved environmental stress tolerance is essential to all breeding programs. Plants that can tolerate extreme weather conditions, including drought, heat, and frost will also 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 brought into 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 avoiding 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 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 environmental problems, such as disease outbreaks. Farmers in the US often do this with maize hybrids to spread the risk of adverse weather during pollination, for example. Plant breeders can develop multi-lines to increase crop diversity and ensure a wider coverage of environments (or races of 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, in-field diversity is one way to hedge one's bets.

Breeding plants to improve the environment

Modern agriculture in the United States is highly industrialized; technology and purchased inputs maintaining current high levels of production. This high production comes with environmental costs including soil erosion, deterioration of soil health, water pollution from nutrients and chemicals, and loss of biodiversity. Plant breeders can help to address these problems by developing new cultivars and new crops that will lead to the sustained health of our agricultural system. Further, making breeding choices based on the needs of the overall cropping system can present breeding opportunities that will lead to improvements in the environment.

1. *Breeding for new uses*

Plant breeders can tackle specific environmental problems by developing plants with new uses using classical plant breeding, possibly with the help of 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, 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. Plant breeding is also essential to adapt new species that have potential to be cleaner, high energy biofuel crops.

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 the people that will use that plant in the environment in the selection process. Directly breeding on-farm with the full participation of farmers and plant breeders is one method to focus breeding efforts on specific traits, locations, and needs.

3. *Breeding for optimum cropping systems*

We typically select for crops within a given cropping system; that is, selection and evaluation of breeding materials are done in fields cultivated using the most common management practices. Changes in cropping systems to make them more environmentally benign may also require changes to selection methods. For example, no-tillage systems may have colder soils in spring, different diseases and disease timing, and other changes relative to conventional tillage, but breeders can change their methods 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 ones, such as an intercropping system of two or more species growing in the same field at the same time, by using different breeding methods to adequately select for productivity under the new cultural practices.

4. *Breeding alternative crops*

Breeders working in new cropping systems or landscapes need to develop improved cultivars of alternative crops, ornamentals, trees, and turfgrasses. 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 previously, and will need to be selected now. Cover crops are an important component of organic and other nontraditional agricultural systems to improve soil fertility and to control weeds and soil-borne diseases and pests, but many cultivars in use today are selections from germplasm collections. They have not have been specifically improved to increase their effectiveness and to eliminate negative traits, such as weediness. While commercial breeding programs may not breed crops for which limited market potential exists, this is clearly possible in the public sector. Breeding on alternative crops needs to be conducted in close consultation with agronomists, economists, and marketers, to ensure that the new crop can be profitably grown by the farmers.

Alternatives do not only exist for agronomic systems. 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, in coordination with the private sector. In addition, the NRCS plant material centers have a long history of breeding / selecting material for conservation and erosion control plantings.

5. *Breeding for new agricultural paradigms*

Some scientists have proposed wholesale changes in our farming methods, such as the development and implementation of perennial polycultures of grain crops, to more closely mimic natural ecosystems than do modern industrialized farms. Plant breeders have a major role to play in these systems, by domesticating, or re-domesticating, several 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 be a component of an ultimate perennial polyculture, but developing it in the context of current wheat systems in the US also makes sense in an effort to help limit soil erosion. Again, this is likely 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—grain yield, fiber yield, fruit quality, flower color, etc. 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 scavenging. Simply selecting and breeding urban tolerant trees ensures that the benefits of trees in terms of ecosystem services (e.g. stormwater management, evapotranspirational cooling, mitigation of air quality, etc.) 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 will take a partnership between the public and private sector. The private sector excels at breeding major, profitable crops. 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.

In addition, 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.

Local breeding issues can be addressed in public breeding programs. Large private breeding programs often overlook problems at the local level (for most crops, areas less than tens or hundreds of thousands of acres). These problems may involve specific diseases or races, making chemical control the only recourse for farmers in these areas. Locally bred and adapted varieties likely require fewer inputs and can be fine tuned for cultural practices (such as delayed or early planting) that may reduce erosion and weed pressures and still produce improved yields.

Ultimately, the public sector can take the long view, that can look at the productivity of the overall agricultural system and at its positive and negative externalities, and put resources toward breeding programs that will help ameliorate problems that have arisen in our drive toward an industrialized, high production agriculture. 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

Breeding for environmental harmony clearly has the advantage of interesting various groups that may be antagonistic to traditional agriculture and/or breeding interests. The power of plant breeding to develop plant products that can both improve production and improve the environment needs to be promoted. This will undoubtedly increase the attraction of the field to young people and increase the numbers and quality of students, but it is the responsibility of those concerned about the future of public breeding to communicate the reality of these potential partnerships in order to gain interest and support.

Some groups not currently engaged with plant breeders may become interested in partnering with certain programs to increase public and/or private support. For example, farmers and farm groups associated with organic and sustainable agriculture movements are particularly interested in publicly funded breeding to fit their systems. They have two concerns: (1) the availability of seeds not controlled by agribusiness and (2) the availability of improved seeds for a diversity of crops, not only the major commodities. These groups have been actively lobbying Congress for increased appropriations for breeding in the public sector. Likely other groups can also 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 breeding programs, and (3) graduates that will be hired by industry, academia, the government, or other breeding programs. As public breeders, we need to deliver improved germplasm and cultivars and ensure they end up on farms, nurseries, and ultimately, dinner plates and landscapes. If we don't, we have failed, and our role in the agricultural research environment should be questioned. If we do, the value of our discipline will be obvious to all. Both cultivar development and scientific research are essential if the public programs are to adequately train new plant breeders.